MINE GASES AND EXPLOSIONS

TEXT-BOOK FOR SCHOOLS AND COLLEGES
AND FOR
GENERAL REFERENCE

BY

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To His Friend

Mr. James Ashworth, M.E.

This Book is Dedicated

With Many Pleasant Recollections,

By The Author

PREFACE

Since the publication of the author's first book on the Ventilation of Mines in 1894, he has written numerous short articles, which have appeared from time to time, bearing on the general subject of Ventilation, including, besides the treatment of the theory and practice of all classes of ventilating machinery and appliances, a detailed study of mine gases, their occurrence, properties, and detection, together with the allied subjects of mine explosions, safety lamps, illuminating oils, etc.

Several of these articles were published in pamphlet form and distributed. The increasing demand for more copies of these little pamphlets and numerous requests that the subject matter they contained be printed in book form has suggested the expediency of revising the former book, the first edition being now exhausted. In doing this it became apparent that the general subject should be divided and treated under two heads, so as to form two separate books, one entitled Mine Gases and Explosions and the other Ventilation of Mines.

The aim in each of these books is to present a practical subject in a practical way, so that the text will breathe forth the very atmosphere of the mine. The elements of physics and chemistry are explained, so far as they relate to the subject of air and gases, in such a manner as to make clear the behavior of the latter in the mine. Sufficient of the history of the subject is given to show the thread of the development in all points of interest, but history is not given for the sake of history alone.

One of the chief aims has been to establish and use throughout the entire text, and in compiling the tables, a set of constants and values that are reliable and used by the best authorities, and that at the same time correspond. The author hopes that this feature of these books, combined with their practical setting, will commend them to technical students desirous of obtaining a working knowledge of the subject of Ventilation.

The author acknowledges with much pleasure and with deep gratitude the valuable assistance given him by Mr. James Ashworth, Old Colwyn, England, who generously contributed a number of photographs of safety lamps, together with much valuable information on this and other portions of the subject; also the assistance of Mr. J. J. Clark, Dean of Faculty, International Correspondence Schools, Scranton, Pa., and Dr. S. W. Stratton, Director of the Bureau of Standards, Washington, D. C., together with a large number of mine inspectors, superintendents, foremen, and fire bosses, who have at all times lent their aid and afforded the author opportunities for investigations that he could not otherwise have made. To all of these he extends heartfelt thanks.

J. T. Beard.

Scranton, Pa., May 1, 1907.

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MINE GASES AND EXPLOSIONS

MINE GASES

INTRODUCTION

1. **Natural Conditions.**—The subject of Mine Gases is preliminary to that of Mine Ventilation; the latter is not complete without the former. The efficient ventilation of a mine requires the removal of the gases that are generated in the mine and those that flow from the strata; the removal of these gases is effected through the agency of a current of air circulated through the mine and known as the *air-current* or *ventilating current.* There always exist in mines important natural *conditions* relating not only to the strata but to the atmosphere and the gases themselves, which affect the efficient ventilation of the mine. Such conditions arise from the existence of gas in the strata enfolding the coal or in the seam itself, the nature of the gases thus confined, and the changes of atmospheric pressure, which affect their outflow from the strata into the mine air.

2. **Natural Laws.** — There are besides numerous natural laws, both chemical and physical, that play an important part in determining the condition of the atmosphere of a mine and thus form a vital part of the subject of Ventilation. Such are the laws of chemical affinity, the constitu-

tion of matter, chemical reactions, the laws of heat and its relation to temperature, atmospheric pressure, the relation of the volume and density of air and gases to their temperature and pressure, and the laws relating to the emission and diffusion of gases.

The generation of gases in the mine, their behavior and properties, and the means used to detect their presence and avoid the dangers they present, form likewise a preliminary study to the Ventilation of Mines.

3. Occurrence of Mine Gases.—The gases met with in mines and which contaminate the mine air are either formed in the mine by the slow combustion of fine coal or other carbonaceous matter in the waste, or are produced by mine fires, the explosion of powder, burning of lamps, decay of timber, breathing of men and animals, etc.; or they exude as natural gas from the strata. The various forms of combustion (oxidation) that are continually going on in the mine consume the oxygen of the mine air, and the remaining large quantities of nitrogen form no small proportion of the mine gases that must be removed by the means of ventilation.

4. Important Mine Gases.—Following are the most important of the mine gases, given in the order of their importance with respect to health and safety in the mine, together with the chemical symbol of each gas, its specific gravity referred to air, the density referred to hydrogen, and the molecular weight of the gas. It will be observed that the molecular weight of hydrogen being 2, the density of each gas referred to hydrogen is one-half its molecular weight. These gases are fully described in Chapter IV.

To understand thoroughly the behavior of mine gases it is necessary to study carefully the physical laws affecting them.

TABLE 1

IMPORTANT MINE GASES

Gas	Symbol	Specific Gravity Air = 1	Density H = 1	Molecular Weight
Methane Light carbureted hydrogen Marsh gas	CH_4	.559	8	16
Carbon monoxide Carbonic oxide	CO	.967	14	28
Carbon dioxide Carbonic acid	CO_2	1.529	22	44
Hydrogen sulphide Sulphureted hydrogen	H_2S	1.1912	17	34
Olefiant gas Ethylene Ethene	C_2H_4	.978	14	28
Ethane	C_2H_6	1.0366	15	30
Nitrous oxide (laughing-gas)	N_2O	1.525	22	44
Oxygen	O_2	1.1056	16	32
Nitrogen	N_2	.9713	14	28
Hydrogen	H_2	.06926	1	2

CHAPTER I

THE CHEMISTRY AND PHYSICS OF GASES

5. Chemistry is that branch of science that treats of the composition of substances and the alterations they undergo by a change in the kind, number, and relative position of their atoms. Chemistry considers the force (*affinity*) that binds atoms together to form molecules, the union and dissociation of atoms, their interchange or rearrangement to form new molecules; and studies the properties of the different substances thus formed.

The study of chemistry as outlined in the following pages has a most important bearing on the subject of Mine Gases and Explosions, and is necessary to a thorough and intelligent understanding of the principles and practice of the ventilation of mines.

6. Physics is that branch of science that treats of the relation of force to matter; the physical constitution of matter; and studies the nature and effects of the forces acting on matter and the changes they produce.

The relation of chemistry to physics is thus seen to be very close; each year the study of physical chemistry is becoming of greater interest, as furnishing facts of vast importance to practical operations and industries. Present knowledge of these subjects is very incomplete, and it is often difficult to discriminate between theories that are still regarded as problematical and those that have been so far authenticated as to have been generally accepted. The atomic theory of Dalton ranks to-day in the latter class, while the later theory of electrical dissociation or *ionization* has not as yet reached that stage of development that its nature and limits are clearly defined. It has, however, long since earned its right to consideration and is steadily gaining favor. So much cannot be said of certain theories of so-called corpuscles, assumed to be the ultimate particle, in the hope of explaining the differences in elementary atoms.

MATTER

7. Matter is substance, aggregation of elemental atoms the existence of which is perceived by sense, or may be demonstrated by deduction; in other words, *matter is what composes the universe.* **Mass** is amount of matter; the mass of a body is the amount or quantity of matter it contains. **Density** is degree of concentration of matter; hence the quantity of matter in a given volume of a body determines its density.

8. **State of Matter.**—There are two *general* conditions of matter, which are described as *solid* and *fluid*, and the latter is again subdivided into the *liquid* and *gaseous*. Matter, therefore, exists in three states or conditions—the *solid*, *liquid*, and *gaseous*. Matter in the solid state is characterized by the comparative rigidity or fixedness of its molecules, which move among themselves with difficulty. The fluid state of matter (liquids and gases) is characterized by the ease with which the molecules of the matter move among themselves.

The same matter may exist in any or all of these forms, accompanied with a change in density. The two agencies that are effective in producing a change in form from one state to another are *heat* and *pressure;* these act in opposite ways and produce opposite effects. An increase of *heat* in a substance acts to drive the molecules farther apart and increases their rapidity of motion, causing expansion and decreasing the density of the substance. On the other hand, an increase of *pressure* drives the molecules nearer together and increases the density of the substance. Cold, or the absence of heat, united with pressure constitutes the most powerful means of increasing the density of matter. For example, water exists as ice at temperatures below 32° F., and as steam at temperatures above 212° F., at sea-level. Air, hydrogen, or other like substances that exist as gases at ordinary temperatures and pressures may be changed to a liquid or even a solid by a decrease of temperature combined with an increase of pressure. By the same agency, also, the temperature at which a given solid is converted into a liquid (melting-point), or the temperature at which a given liquid is changed into a gas or vapor (boiling-point) is lowered by a decrease of pressure and raised by an increase of pressure.

9. **Divisions of Matter.**—The smallest conceivable division of matter is called an *atom*, and two or more atoms chemically combined form a *molecule*. Recently science has demonstrated the fact that matter is capable of still other divisions than the atom and molecule, and these resulting particles are called *ions*.

The **ion** is the result of an electrical division of matter. It is an electrically charged particle, and may bear a charge of positive electricity, when it is called a *cation;* or of negative electricity, when it is called an *anion*. Ions may be elemental in character like atoms, or complex like radicals. When deprived of their electrical charge they again assume molecular condition.

The **atom** is the smallest particle that is assumed to take part in a chemical reaction, by which is understood an interchange of the atoms forming molecules of unlike substances. An atom, it is assumed, cannot exist in a free or uncombined state, except as an *ion* when electrically charged.

The **molecule** is the smallest particle that is assumed to exist in a free or uncombined state, except when such particles are electrically charged as *ions*. *Like* atoms unite to form **simple molecules**; *unlike* atoms form **compound molecules.**

10. The Elements.—At present there are 78 kinds of matter known to the chemist; these are called *elements*. **Elementary matter** is that composed of simple molecules only, or molecules whose atoms all consist of the same kind of matter. When the atoms forming the molecules of a substance are of two or more kinds of matter, the substance is a **compound.**

A compound substance may be either a *mechanical mixture* or a *chemical compound*. Where the molecules of two or more unlike substances or kinds of matter are simply *mixed*, and exist side by side, and do not act on each other chemically, but each retains its original identity, and may be separated by suitable means without in any way undergoing change, the compound is a **mechanical mixture.** It differs from a chemical compound in that the different kinds of matter forming it are *mixed in any proportion*, and the properties of the mixture vary with the amounts of the several ingredients.

A **chemical compound** always possesses the same properties, because the components are always *combined in fixed proportions*.

Table 2 on the following page gives the names of all the elements known at the present time, together with their symbols and atomic weights referred both to hydrogen and to oxygen as units.

Table 2

ATOMIC WEIGHT OF THE ELEMENTS

Element	Symbol	Atomic Weight		Element	Symbol	Atomic Weight	
		H=1	O=16			H=1	O=16
Aluminum	Al	26.9	27.1	Neodymium	Nd	142.5	143.6
Antimony	Sb	119.3	120.2	Neon	Ne	19.9	20.
Argon	A	39.6	39.9	Nickel	Ni	58.3	58.7
Arsenic	As	74.4	75.	**Nitrogen**	**N**	13.93	**14**.04
Barium	Ba	136.4	137.4	Osmium	Os	189.6	191.
Bismuth	Bi	206.9	208.5	**Oxygen**	**O**	15.88	**16.**
Boron	B	10.9	11.	Palladium	Pd	105.7	106.5
Bromine	Br	79.36	79.96	Phosphorus	P	30.77	31.
Cadmium	Cd	111.6	112.4	Platinum	Pt	193.3	194.8
Cæsium	Cs	131.9	132.9	Potassium	K	38.85	39.15
Calcium	Ca	39.8	40.1	Praseodymium	Pr	139.4	140.5
Carbon	**C**	11.91	**12.**	Radium	Rd	223.3	225.
Cerium	Ce	139.2	140.25	Rhodium	Rh	102.2	103.
Chlorine	Cl	35.18	35.45	Rubidium	Rb	84.9	85.5
Chromium	Cr	51.7	52.1	Ruthenium	Ru	100.9	101.7
Cobalt	Co	58.55	59.	Samarium	Sm	149.2	150.3
Columbium	Cb	93.3	94.	Scandium	Sc	43.8	44.1
Copper	Cu	63.1	63.6	Selenium	Se	78.6	79.2
Erbium	Er	164.8	166.	Silicon	Si	28.2	28.4
Fluorine	F	18.9	19.	Silver	Ag	107.11	107.93
Gadolinium	Gd	154.8	156.	Sodium	Na	22.88	23.05
Gallium	Ga	69.5	70.	Strontium	Sr	86.94	87.6
Germanium	Ge	72.	72.5	**Sulphur**	**S**	31.82	**32**.06
Glucinum	Gl	9.03	9.1	Tantalum	Ta	181.6	183.
Gold	Au	195.7	197.2	Tellurium	Te	126.6	127.6
Helium	He	4.	4.	Terbium	Tb	158.8	160.
Hydrogen	**H**	**1.**	1.008	Thallium	Tl	202.6	204.1
Indium	In	114.1	115.	Thorium	Th	230.8	232.5
Iodine	I	126.01	126.97	Thulium	Tm	169.7	171.
Iridium	Ir	191.5	193.	Tin	Sn	118.1	119.
Iron	Fe	55.5	55.9	Titanium	Ti	47.7	48.1
Krypton	Kr	81.2	81.8	Tungsten	W	182.6	184.
Lanthanum	La	137.9	138.9	Uranium	U	236.7	238.5
Lead	Pb	205.35	206.9	Vanadium	V	50.8	51.2
Lithium	Li	6.98	7.03	Xenon	Xe	127.	128.
Magnesium	Mg	24.18	24.36	Ytterbium	Yb	171.7	173.
Manganese	Mn	54.6	55.	Yttrium	Yt	88.3	89.
Mercury	Hg	198.5	200.	Zinc	Zn	64.9	65.4
Molybdenum	Mo	95.3	96.	Zirconium	Zr	89.9	90.6

For the sake of easy reference the elements used in this book and which are of the most importance to the student of ventilation are set in heavy-faced type, together with their symbols; the atomic weights of these elements commonly used are likewise set in heavy-faced type.

11. **Forces Inherent in Matter.**—**Affinity** is a chemical force acting to bind atoms together to form molecules. The atoms of the several elements have a greater or less affinity for each other, causing them to form compounds more or less stable, according to the strength of the affinity of the combining atoms. Water is one of the most stable compounds, because of the great affinity of the hydrogen and oxygen atoms forming the molecule of water. The separation of the atoms forming a molecule is called **dissociation,** which is the reverse of what takes place when the atoms combine.

The various forms of **attraction** are known as *gravitation*, *cohesion*, *adhesion*, and *magnetism;* these forces are exerted between molecules or masses of matter.

12. **Gravitation** is the attraction that exists between the earth and all bodies on and around it. The attraction is mutual, and since the mass of the earth is constant the attractive force is directly proportional to the mass of the body. Where the latter is free to move, it falls in a straight line which, if continued, would pass through the center of the earth's mass.

13. **Cohesion** and **Adhesion** are the forces that bind molecules together, giving to matter its form and continuity. Cohesion, however, binds together the *molecules* of *like* matter, while adhesion joins the *surfaces* of like or unlike matter. Thus, *cohesion* holds together the molecules of glue, while adhesion causes the glue to adhere to other substances, such as wood or other like material.

14. **Magnetism** is the term employed to denote the cause, as well as the resulting phenomena, of the attraction and repulsion some substances have for other substances. This attraction was first observed in magnetic iron oxide.

PROPERTIES OF MATTER

15. **Constitution of Matter.**—The theory most widely accepted in modern times as best explaining all the various phenomena of matter is that known as the *atomic theory* proposed by Dalton in 1808, and which conceives of all matter as made up of parts or atoms capable of motion among themselves, and possessing a greater or less degree of attraction for each other. This condition or state considers what may be called the chemical division of matter, and is, we may assume, sufficient for the full explanation of the various chemical changes that take place in matter, and the physical effects of heat, causing expansion or contraction, and tension or pressure, in a body. It will be assumed, also, that the consideration of this condition of matter is sufficient for the purposes of this volume, although it has been suggested by an eminent authority (Ashworth) that it is possible a closer study of the electrical division of matter may furnish a more adequate and satisfactory explanation of some of the phenomena attending large mine explosions. This does not seem improbable since, as far as investigation has gone, the forces concerned in the electrical division of matter appear more powerful by far than any of the physical or chemical forces known to us. However, this condition of matter has not as yet been sufficiently analyzed to form a part of a concrete science.

16. **Volume.**—The volume of a body is the space it occupies. The volume of a body of regular shape may be

calculated by finding the product of its several dimensions in accordance with the rules of mensuration. When a body is of irregular shape, its volume is determined practically by measuring the quantity of liquid it displaces when immersed in a liquid in which it is insoluble. The volume of any body is always equal to its displacement when immersed.

17. **Mass.**—Mass is amount of matter; the mass of a body is the amount of matter forming the body.

18. **Density.**—In a general sense density is compactness of mass, or mass per unit of volume. In a more specific sense density is the relative degree of compactness of matter, and has reference to the amount of matter in a given volume of a body as compared with the amount of matter in a like volume of another body taken as a standard or *unit.* The densities of the several mine gases referred to hydrogen as unity are given in Table 1; from this table it is observed that methane is 8 times, oxygen 16 times, and carbon monoxide, olefiant gas, and nitrogen each 14 times as dense as hydrogen gas. In other words, these gases contain severally 8, 16, and 14 times as much matter as hydrogen, volume for volume.

19. **Compressibility.**—The effect of pressure on matter is to press its molecules nearer together and thus reduce its volume. All forms of matter are not alike compressible, gases being most and liquids least compressible. The compressibility of a body is evidence of its porosity, or of the space between its molecules, and reveals the possibility of these molecules moving freely among themselves, which molecular motion is independent of any motion of the body itself. The compression of most gases beyond a certain limit changes the gas to a liquid. A reduction of temperature always greatly assists these changes,

owing to the abstraction of heat from the matter compressed.

20. Elasticity.—The elastic force of a body is the force with which its molecules resist compression. The elastic force of a gas is called the *pressure* or *tension* of the gas; heat increases the tension of all gases, which thus require a greater force to compress them as the temperature is increased. As before (Art. 19), gases are the most elastic and liquids the least so of all the forms of matter.

21. Viscosity.—The particles of all fluids always adhere slightly to each other and when put in motion attempt to drag adjacent particles along, or, conversely, hold them back from being drawn away. This property is called *viscosity*, and when highly marked, a liquid is said to be "viscous," sticky or adhesive. Gases, also, possess more or less viscosity. The viscosity of air greatly increases the frictional resistance of airways through which the current passes.

22. Porosity.—This term relates to the pores of a solid body, or the spaces that exist naturally between the molecules of such a body. All solids are more or less porous. The porosity of a body determines the ease with which air, water, or other fluids will pass through it or be absorbed by the solid.

23. Capillary Action.—This term describes the attraction that takes place between a liquid and a solid when the two are brought in contact with each other. It is owing to the force of capillary attraction that liquids are absorbed in the pores of a solid and drawn upward, the capillary force overcoming the force of gravity. The action is strongest in fine capillary tubes, from which cause its name is derived. Capillary attraction varies inversely as the diameter of the pores, and is also different for different liquids and solids. In some cases, instead of attraction, repulsion takes place between the liquid and the solid; for example, attraction results between glass and water after the glass has been wet, but repulsion between glass and mercury. The attraction or repulsion will depend on whether or not the liquid wets the solid.

24. **Transpiration, Diffusion.**—Transpiration, otherwise called *effusion*, relates to the passage or flow of a fluid through the pores of a solid, as the outflow of gas from an exposed face of coal. Diffusion relates to the intermixing of the molecules of fluids in contact with each other, as the diffusion of the mine gases into the air and into each other in the mine. These important properties of gases will be studied in detail later.

25. **Conductivity.**—Conductivity is the power of matter to convey or transmit any molecular sensation or condition from one molecule to another. It varies greatly in different kinds of matter, and indicates in a general way the resistance such matter offers to transmission.

26. **Inertia.**—Inertia is that property of matter by virtue of which a body remains in a state of rest or motion till acted on by a force. Matter at rest will remain at rest till some force acts on it and imparts to it motion; matter in motion will continue to move till some resisting force brings it to rest. Inertia is therefore of two kinds, *inertia of rest* and *inertia of motion.*

27. **Heat** is a condition of matter caused by an exceedingly rapid oscillatory or vibratory motion of its molecules, and manifesting itself as a particular sensation, which the human senses discern as temperature. The intensity of the heat is directly proportional to the velocity and amplitude of the vibrations. A hotter body in contact with a colder one imparts to the latter more molecular motion

than it receives, and the loss of the hotter body in energy is the exact equivalent gained by the colder body. In a generic sense the term describes a condition or state of matter that is capable of being measured as energy is measured; and so we determine the *quantity of heat* in a body as we would measure the amount of energy. It is in this sense that the term is used in science. (See Chapter II.)

28. **Weight.**—Weight or gravity are terms used to describe the effect produced or the property conferred on matter by virtue of the attraction of the earth. Hence weight is a property that all matter possesses by virtue of the attraction of the earth. The weight of a body is the static measure of the force of gravitation exerted on that body; and since this force is exerted alike on each unit of mass, the weight of a body is always proportional to its mass, at the same place. It is evident that if all matter were of equal density the weights of equal volumes of all matter would be equal; but as this is not the case, the relative weights of equal volumes of matter express the relative densities of such matter. The English unit of weight is the pound, but owing to the variation of the force of gravity this is not an absolute unit.

29. **Atomic Weight.**—Dalton's atomic theory ascribes weight to every atom, but the size of an atom being inappreciable its weight cannot be expressed in units of any denomination; so that the actual weight of an atom of any kind of matter is at present mere speculation. By means of many careful gravimetric and volumetric determinations, however, the relative weights of different kinds of matter have been accurately ascertained. Hydrogen has been found to be the lightest form of matter known, and the hydrogen atom has therefore been chosen as the

unit of atomic weight; the weights of the other atoms are expressed in terms of this unit. Hence atomic weight is only relative weight, expressed in terms of the weight of an atom of hydrogen. Thus the atomic weight of hydrogen being 1, that of nitrogen is 14, oxygen 16, etc. It will be seen presently that the atomic weights of the simple mine gases are the same as their densities.

30. Molecular Weight.—Molecular weight is the sum of the atomic weights of the atoms forming a molecule. The molecular weights of the common mine gases given in Table 1 will be seen later to be equal in each case to the sum of the atomic weights of the combining atoms, and in the case of the simple mine gases, hydrogen, nitrogen, and oxygen, the molecular weight in each case will be found to be twice the atomic weight of the gas.

31. Atomic and Molecular Volumes, Specific Volume.—The same careful gravimetric and volumetric determinations of matter previously referred to in relation to atomic weight have established the law of volume that has since come to be known as Avogadro's law: *Equal volumes of gases at the same temperature and pressure contain the same number of molecules*. This is equivalent to stating that all gaseous molecules at the same temperature and pressure are of the same size. This law applies without exception to all the mine gases, and is of importance in determining the relative volumes of air and gases consumed and of gases produced in any chemical reaction. Chemical hypothesis assumes that all simple gaseous molecules contain two atoms each, and while a compound molecule may contain any number of atoms it is still of the same size as the simple molecule, or twice the size of the hydrogen atom. Hence calling the volume of the hydrogen atom 1, the volume of any gaseous molecule is 2, whatever the number of atoms it may contain. Atomic and molecular volumes, sometimes called **specific volumes,** are simply relative volumes, as atomic and molecular weights are relative weights.

Since the atomic weight of hydrogen is 1, its molecular weight is 2; and since all gaseous molecules under like conditions are of equal size, the molecular weight of any gas may be compared with the molecular weight of hydrogen to ascertain the density of such gas, which density will therefore be one-half the molecular weight of the gas, the density of hydrogen being unity.

SPECIFIC GRAVITY

32. The term **specific gravity** means *the ratio of the weight of any given volume of a substance to the weight of an equal volume of another substance taken as a standard.* This term has practically the same meaning as density, but compares the *weights* of equal volumes, while density relates directly to the *masses* of equal volumes of different solids, liquids, or gases. Density is, therefore, *relative mass*, while specific gravity is *relative weight.* Each of these terms has its own particular significance, which should determine its use; the terms should not be used interchangeably, as they are by some writers. In a general sense, however, the density of a body is made known by ascertaining experimentally its specific gravity. While density depends upon a purely assumed basis, specific gravity has a gravimetric value that is tangible. Calling the density of hydrogen 1, that of nitrogen is 14, which means that nitrogen contains fourteen times as much matter, volume for volume, as hydrogen, on the assumed chemical hypothesis. Again, the specific gravity of nitrogen referred to air as unity is .9713, which means that any given volume of nitrogen weighs but .9713 of the weight of an equal volume of air, under the same conditions of temperature and pressure. It is evident from the foregoing that the density of air referred to hydrogen as unity is 14 ÷ .9713 = 14.4, as shown in another way later (Art. 43).

33. Methods of Determining the Specific Gravity of Solids, Liquids, and Gases.—These may be divided into three classes, according to the kind of apparatus used; namely: 1. Method by balances. 2. Method by specific-gravity bottle. 3. Method by hydrometer. All of these methods depend on the principle of Archimedes. When a body is submerged in water the volume of water displaced is always equal to the volume of the body itself, and Archimedes discovered that the buoyant or upward pressure exerted on the submerged body—its loss in weight—is equal to the weight of the water displaced. This principle is clearly demonstrated by what is known as the hydrostatic balance, shown in Fig. 1. A solid cylinder *a* is

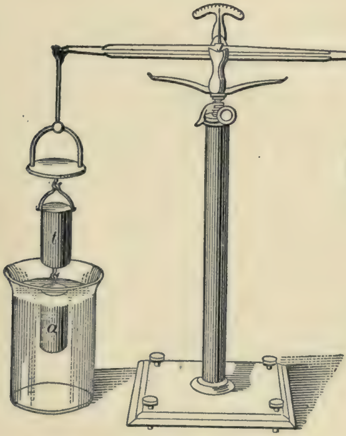

Fig. 1.—The Hydrostatic Balance.

suspended from the bottom of an empty cup *t*, which hangs beneath one of the scale-pans of a balance. The volume of the cylinder is exactly equal to the capacity of the cup, and their weight is balanced by the weights in the opposite scale-pan. Water is now poured into the jar until the solid cylinder is completely submerged, which causes the scale-pan on that side of the balance to rise, but by now filling the empty cup *t* with water the balance is again restored, showing that the upward pressure on the submerged cylinder is equal to the weight of the water displaced.

34. Method by a Balance.—This method is shown in Fig. 2, and is practically what has just been explained. The substance whose specific gravity is to be determined is suspended beneath one scale-pan and its exact weight (W) found by weights placed in the opposite pan. Water is then poured into the glass and the weight (w) of the submerged body found. The difference ($W-w$) of these weights is the weight of the displaced water, whose volume is equal to the volume of the substance. The specific gravity is then the ratio of the weight of the substance in air to its weight in water; or

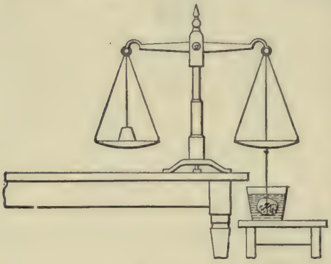

FIG. 2
Determining Specific Gravity by a Balance

$$\text{Sp. gr.} = \frac{W}{W-w} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

To determine the specific gravity of a liquid by a balance, the weight of a coin or other substance is found first in air (W), then in water (w_1), and afterwards in the liquid (w_2) whose specific gravity is to be determined. Then, since $W-w_2$ equals the weight of a certain volume of the liquid, and $W-w_1$ equals the weight of an equal volume of water, the specific gravity of the liquid is the ratio of the former to the latter; or

$$\text{Sp. gr.}=\frac{W-w_2}{W-w_1}. \quad . \; . \; . \; . \; . \; . \quad (2)$$

To determine the specific gravity of a gas by a balance, a glass globe of any given capacity is used, being provided with a stop-cock in the neck, by means of which it may be closed after the air has been exhausted with an air-pump. The weight of the globe is found first empty (w), then filled with air (W_1), and finally filled with the gas (W_2) whose specific gravity is to be determined. Then, since W_2-w is the weight of a certain volume of the gas, and W_1-w is the weight of an equal volume of air, the specific gravity of the gas is the ratio of the former to the latter; or

$$\text{Sp. gr.}=\frac{W_2-w}{W_1-w}. \quad . \; . \; . \; . \; . \; . \quad (3)$$

To determine the specific gravity of a liquid, or of any solid in fine grains or powder, a glass bottle is used (Fig. 3) provided with a ground glass stopper perforated with a fine capillary bore for the escape of any excess of liquid.

To determine the specific gravity of a liquid the weight of the bottle is found first empty (w), then filled with water (W_1), and finally filled with the liquid (W_2). The specific gravity of the liquid is then given by formula 3, above.

To determine the specific gravity of a solid in grains or powder its exact weight (W) is first found, then the weight (w_1) of the bottle filled with water, and finally the weight (w_2) of the bottle filled with water and containing also the substance. Then the specific gravity of the substance is the ratio of the weight (W) of the substance to the weight ($W+w_1-w_2$) of the water displaced from the bottle when the substance was introduced; or

FIG. 3
Specific-gravity Bottle

$$\text{Sp. gr.} = \frac{W}{W+w_1-w_2}. \quad \quad (4)$$

If a substance is soluble in water its specific gravity may be determined by using, instead of water, another liquid in which it is insoluble and afterwards finding the specific gravity of such liquid. The product of these two specific gravities will be the specific gravity of the substance referred to water.

35. Method by the Hydrometer.—There are two types of the hydrometer used. The **Nicholson** or **Fahrenheit hydrometer** (Fig. 4) has a constant immersion or displacement but a variable weight, small weights being added to the scale-pan *a* at the top of the stem *c*, to sink the hydrometer to the standard mark upon the stem. This hydrometer is provided with a lower scale-pan *d* and can be used to determine the specific gravity of a solid insoluble in and heavier than water. The solid whose specific gravity is to be determined is first placed in the upper scale-pan and a sufficient number of weights added to sink the hydrometer to the mark. This weight subtracted

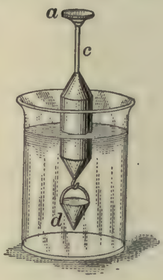

FIG. 4
The Nicholson or Fahrenheit Hydrometer

from the weight required to sink the hydrometer alone to the mark will give the weight of the substance in the pan. The substance is now removed to the lower pan, where it will be immersed in the water and thus add to the displacement. It will now require a less weight to sink the hydrometer to the mark, and the difference is the weight of the water displaced. The weight of the substance divided by the weight of the displaced water will give the specific gravity of the substance.

To determine the specific gravity of a liquid by this hydrometer, the sum of the weight of the hydrometer (W) and the additional weights (w_2) required to sink the hydrometer in the liquid is divided by the sum of the weight of the hydrometer and the weights required to sink the same in water ($W+w_1$); thus,

$$\text{Sp. gr.} = \frac{W+w_2}{W+w_1}. \qquad \dots\dots \qquad (5)$$

The *Baumé hydrometer* (Fig. 5), unlike the Nicholson, has a constant weight but a variable immersion, the stem being graduated to read the strength of the liquid to a scale called the Baumé scale. Both of these hydrometers are weighted to maintain them in a vertical position in the liquid.

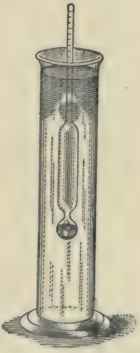

FIG. 5
The Baumé Hydrometer

36. Specific Gravities of Various Substances.—The following table gives the specific gravities and the weights per cubic foot of many common solid and liquid substances. The weights per cubic foot of most of the substances in this table are calculated from the weight of one cubic foot of water at its maximum density (39.2° F.), namely, 62.425 pounds.

TABLE 3

SPECIFIC GRAVITIES AND WEIGHTS OF SUBSTANCES

Substance	Average Specific Gravity, Water = 1	Average Weight, Lbs. per Cu. Ft.
Alcohol, pure	.793	49.5
Aluminum	2.66	166.
Asphalt, 1 to 1.8	1.4	87.4
Brass, cast, 7.8 to 8.4	8.1	505.64
" rolled	8.4	524.37
Coal, anthracite, 1.3 to 1.7 (solid)	1.5	93.64
" bituminous, 1.2 to 1.5 (solid)	1.35	84.27
Copper, cast, 8.6 to 8.8	8.7	543.
" rolled, 8.8 to 9	8.9	555.58
Gold, cast	19.258	1202.28
Ice	.92	57.44
Iron, cast, 6.9 to 7.4, usually assumed	7.21	450.
" wrought, 7.6 to 7.9, usually assumed	7.77	485.
" rolled, usually assumed	7.69	480.
Lead, 11.3 to 11.47	11.38	710.4
Limestone	2.7	168.55
Lime, quick	1.5	93.64
Mercury, 32° F.	13.594	848.61
" 62° F.	13.555	846.17
Petroleum	8.878	55.42
Powder, black (blasting)	.923	57.62
Platinum, 21 to 22	21.5	1342.14
Sandstone, dry, 2.1 to 2.7	2.4	150.
Shale, 2.4 to 2.8	2.6	162.3
Slate, 2.7 to 2.9	2.8	175.
Silver	10.5	655.55
Steel, 7.7 to 7.9, assumed	7.85	490.
Tar	1.	62.425
Trap-rock	3.	187.27
Tin, cast, 7.2 to 7.5	7.35	458.82
Water, pure rain or distilled	1.	62.425
" sea, 1.026 to 1.03	1.028	64.17

37. Difference between Atomic Weight and Specific Gravity.—The question is often asked, Why is platinum, whose atomic weight is 194.8, so much heavier than lead, whose atomic weight is 206.9, platinum weighing 1,342 pounds per cubic foot, while lead weighs but 710 pounds? The reason is, that like volumes of either solids or liquids do not of necessity contain the same number of molecules.

Avogadro's law (Art. 31) is true only of gases; the specific gravities of *gases* are, with one or two unimportant exceptions, proportional to their molecular weights, or in the case of simple gases, the specific gravity of the gas is proportional to its atomic weight. But the molecules of *solids* are massed together so that the specific gravity of the solid bears no relation to its atomic weight.

38. The Use of Specific Gravity.—The specific gravity of a body, solid, liquid, or gas, is the ratio of its weight to the weight of an equal volume of another body taken as a standard. Water is usually assumed as the standard for solids and liquids, and its weight is commonly taken as 62.5 pounds per cubic foot; but when extreme accuracy is desired the exact weight of water at its maximum density (39.2° F.) is taken, which is 62.425 pounds. The standard for gases is air, at the same temperature and pressure. Knowing the weights of these standards the weight of a given volume of any solid, liquid, or gas is found by multiplying the weight of a cubic foot or the *unit weight* of the standard by the specific gravity of the solid, liquid, or gas, and that product by the given volume according to the following:

RULE.—(*a*) *For Solids or Liquids.—Multiply the unit weight of water (62.5 lb.) by the specific gravity of the solid or liquid, and that product by its volume; the last product will be the weight of the given volume of the solid or liquid.*

(*b*) *For Gases.—Multiply the unit weight of air, at 32° F., bar. 29.92 inches (.080728 lb.), by the specific gravity of the gas and that product by its volume; the last product will be the weight of the given volume of the gas at the same temperature and pressure.*

Or expressed as a formula this rule is

$$W=(w\times G)V. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

W = required weight of substance (lb.);
w = unit weight of standard (lb. per cu. ft.);
V = volume of substance (cu. ft.);
G = specific gravity of substance.

Example 1.—Find the weight of 10 cubic feet of bituminous coal having a specific gravity of 1.27.

Solution.—Substituting the given values in formula 6 the required weight is

$$W = (62.5 \times 1.27)10 = 793.75 \text{ lb.} \quad \textit{Ans.}$$

Example 2.—A piece of anthracite coal weighing 15 pounds is found by trial to displace when immersed an amount of water weighing exactly 10 pounds; what is the specific gravity of the coal?

Solution.—Since the coal when immersed displaces its own volume of water, and the specific gravity of the coal is the ratio of its own weight to the weight of an equal volume of water,

$$G = \frac{15}{10} = 1.5. \quad \textit{Ans.}$$

Example 3.—A piece of limerock weighs 16 pounds in air and but 9.6 pounds when immersed in water; what is its specific gravity?

Solution.—Substituting the given values in formula 1, the specific gravity of the limerock is

$$G = \frac{16}{16 - 9.6} = \frac{16}{6.4} = 2.5. \quad \textit{Ans.}$$

Example 4.—A certain silver coin weighing 38 grains in the air, weighed 34.5 grains in water and 35.2 grains in alcohol; calculate the specific gravity of the alcohol.

Solution.—Substituting the given values in formula 2, the required specific gravity of the alcohol is

$$G = \frac{38 - 35.2}{38 - 34.5} = \frac{2.8}{3.5} = .8. \quad \textit{Ans.}$$

Example 5.—A glass globe from which the air was first exhausted weighed empty 1,250 grains; when filled with air at a given temperature and pressure the weight was 1,268.2 grains; when filled with carbon dioxide gas, at the same temperature and pressure, the weight of the globe and gas was 1,277.83 grains; calculate the specific gravity of the gas.

Solution.—Substituting the given values in formula 3, the required specific gravity of the gas is

$$G=\frac{1,277.83-1,250}{1,268.2-1,250}=\frac{27.83}{18.2}=1.529+. \quad \textit{Ans.}$$

Example 6.—Calculate the weight of 100 cubic feet of carbon dioxide gas at 32° F. and a barometric pressure of 29.92 inches of mercury, calling the unit weight of air under these conditions .08073 pound.

Solution.—The weight of 1 cubic foot of air at this temperature and pressure is .08073 pound, and the specific gravity of carbon dioxide gas (Table 1) is 1.529, substituting these values in formula 6,

$$W=100(.08073\times1.529)=12.34+\text{lb.} \quad \textit{Ans.}$$

Example 7.—Calculate the weight of 1 cubic yard of solid sandstone having a specific gravity (Table 3) of 2.4.

Solution.—Taking the weight of a cubic foot of water as 62.5 pounds and substituting values in formula 6, the weight of 1 cubic yard (27 cu. ft.) of sandstone is

$$W=27(62.5\times2.4)=4.050\text{ lb.} \quad \textit{Ans.}$$

CHEMICAL REACTIONS AND EFFECTS

39. If the affinity of the atoms of the different elements were all equal, there would be no tendency of the atoms of different substances to change places, and as a result there would be no such thing as chemical reaction. There is, however, a great difference in the affinity of certain atoms for certain other atoms, and this difference of affinity gives rise to chemical change. The interchange that thus takes place between the atoms of different substances is called **chemical reaction.** Chemical reactions may be expressed in the form of an equation.

40. Symbols.—To properly express these equations, a symbol is employed to designate each of the elements entering into the reaction. Every element is thus expressed by a symbol. This symbol is usually the first letter of the name of the element, as Hydrogen, H; Oxygen, O; Carbon, C; or the first letter of the Latin name, as Potassium (*Kalium*), K; but where two or more elements begin with the same letter a second letter is added, as Calcium, Ca; Copper (*Cuprum*), Cu; Iron (*Ferrum*), Fe, etc. (Table 2.) A symbol standing alone is taken to represent a single atom of the element; two, three, or more atoms are indicated by writing small subscript figures, 2, 3, etc., after the symbol; thus H, H_2, H_3 represent respectively one, two, and three atoms of hydrogen.

41. Chemical Formulas.—A chemical formula is an expression intended to show the chemical composition of a molecule of a given substance. It is always expressed by the symbols of the various elements entering into the composition of the molecule. The number of atoms of each particular element present is indicated by a small subscript figure written after the symbol of such element. The molecules of most elements in the gaseous form are assumed to contain two atoms each, and are so represented in writing the formulas for such molecules; thus, H_2, O_2, N_2 represent respectively a single molecule of hydrogen, oxygen, and nitrogen. Two, three, or more molecules are indicated by writing large figures, 2, 3, etc., before the symbol representing the molecule; thus, $2H_2$, $5O_2$, $6N_2$ represent respectively two, five, and six molecules of hydrogen, oxygen, and nitrogen. A compound molecule may contain any number of atoms greater than one. The following may be mentioned as examples of molecules containing different numbers of atoms:

Carbon monoxide (CO), 1 atom carbon, 1 atom oxygen.	2	atoms
Carbon dioxide (CO_2), 1 atom carbon, 2 atoms oxygen.	3	“
Ammonia (NH_3), 1 atom nitrogen, 3 atoms hydrogen.	4	“
Methane (CH_4), 1 atom carbon, 4 atoms hydrogen.	5	“
Olefiant gas (C_2H_4), 2 atoms carbon, 4 atoms hydrogen.	6	“

The molecules of other substances, particularly organic bodies, may contain a very large number, sometimes upwards of 100 atoms. The chemical formula representing any molecule expresses its composition as determined by chemical analysis. For example, analysis has shown that water is composed of 1 part by weight of hydrogen to 8 parts by weight of oxygen. Since the atomic weight of oxygen has been determined as 16 and that of hydrogen 1, the formula representing a molecule of water must contain two atoms of hydrogen and one atom of oxygen and is therefore H_2O. In like manner the formula for ammonia has been determined as NH_3; sulphuric acid, H_2SO_4; calcium sulphate, $CaSO_4$; olefiant gas, C_2H_4, etc. The formula representing any substance is likewise always determined by analysis, and must be memorized by the student.

42. A Chemical Equation.—Since a chemical reaction is simply an interchange of the atoms forming the molecules of substances, and results in no loss of matter but the formation of new compounds, such a reaction may be expressed by an equation the first member of which contains the formulas of the substances as they were before the reaction took place, and the second member the formulas of the compounds formed by the reaction, or, as we say, the products of the reaction. It is important to observe that, since no matter is lost, the total number of atoms is the same before and after the reaction, and both members of the equation therefore contain an equal number of atoms. As previously explained, the cause of chemical reaction is the greater or less affinity of different atoms for each other; the reaction is usually assisted by heat and in most cases by the presence of moisture. The ease with which chemical reaction takes place varies with different substances. Compounds that resist chemical reaction to a marked degree are called *stable* compounds; others quite susceptible to chemical change are termed *unstable* compounds.

The chemical equation expressing any reaction can only be written when the products of the reaction are known; hence it is often difficult or perhaps quite impossible to express with exactness some reactions since the resulting products vary in kind with the conditions under which the reaction takes place. For example, when methane (CH_4), often called marsh gas, is completely burned in air the oxygen of the air unites with the carbon of the gas to form a new gas, carbon dioxide (CO_2), and with the hydrogen of the gas to form water vapor (H_2O), while the nitrogen of the air remains unchanged. When, however, there is a limited supply of air present some carbon dioxide gas will be formed and (Art. 112) varying amounts of carbon monoxide (CO) and generally some unburned methane will remain mixed with the nitrogen of the air. The relative amounts of these several products will depend wholly on the conditions attending the combustion, and it is therefore not possible to represent this combustion with any degree of exactness.

To write the chemical equation expressing the complete combustion of methane in air, we first write as below the formulas for this gas and for air, for the first member of the equation, and then the formulas for the several products that we know will be formed by the reaction, not attempting to express the amount of each; thus,

$$\overset{\substack{\text{Methane}\\\text{(marsh gas)}}}{CH_4} + \overbrace{\overset{\text{Oxygen}}{O_2} + \overset{\text{Nitrogen}}{N_2}}^{\text{Air.}} = \overset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \overset{\text{Water}}{H_2O} + \overset{\text{Nitrogen}}{N_2}$$

It will be observed that the above equation is not complete, since both members do not contain the same number of atoms, there being 9 atoms in the first and but 8 atoms in the second member. To remedy this trouble we observe the supply of oxygen must be sufficient to satisfy both the carbon and the hydrogen of the methane or marsh gas. Each molecule of this gas contains 1 atom of carbon and 4 atoms of hydrogen. The 1 atom of carbon will take 2 atoms of oxygen to form 1 molecule of carbon dioxide gas; and the 4 atoms of hydrogen will require 2 more atoms of oxygen to form 2 molecules of water, consuming in all 4 atoms or 2 molecules of oxygen. Since, as will be learned later, air contains 4 volumes of nitrogen to 1 volume of oxygen, there will be 8 molecules of nitrogen represented in this reaction. The complete equation will therefore contain 1 molecule of methane, 2 of oxygen, and 8 of nitrogen in the first member; and 1 molecule of carbon dioxide, 2 of water, and 8 of nitrogen in the second member, as follows:

$$CH_4+2O_2+8N_2=CO_2+2H_2O+8N_2. \quad . \quad . \quad . \qquad (7)$$

Each member of this equation contains the same number of atoms; it is therefore the complete equation expressing this reaction. The nitrogen has played no part in the reaction further than the dilution of the other gases.

43. The Use of Chemical Formulas and Equations. A chemical formula shows at once the composition of a substance. Since the formula represents a molecule whose molecular weight (Art. 30) is the sum of the atomic weights of the atoms forming the molecule, and whose molecular volume (Art. 31), in the case of all the mine gases and air, is 2, it is possible from the formula to calculate the density of any of these gases or of air. To do this, first find the molecular weight of the gas as follows:

Molecular weight CO, $12 + 16 = 28$
Molecular weight CO_2, $12 + 2(16) = 44$
Molecular weight NH_3, $14 + 3(1) = 17$
Molecular weight CH_4, $12 + 4(1) = 16$
Molecular weight C_2H_4, $2(12) + 4(1) = 28$

But the density of a gas is always equal to its molecular weight divided by its molecular volume, which gives for the density of each of these gases as follows:

Density CO, $\frac{28}{2} = 14.$
Density CO_2, $\frac{44}{2} = 22.$
Density NH_3, $\frac{17}{2} = 8.5$
Density CH_4, $\frac{16}{2} = 8.$
Density C_2H_4, $\frac{28}{2} = 14.$

To calculate the *specific gravity* of a gas referred to air, it is first necessary to calculate the weight of a volume of air corresponding to a molecule of gas. To do this, we must remember that air is a mechanical mixture and not a chemical compound; the nitrogen and oxygen gases that chiefly form the atmosphere are mixed together in the proportion, by volume, of 4:1. In other words, every 5 cubic feet of air consists of 4 cubic feet of nitrogen mixed with 1 cubic foot of oxygen, and it follows directly from Avogadro's law (Art. 31) that for every 4 molecules of nitrogen there is 1 molecule of oxygen. Therefore, to compare equal volumes of gas and air, we must consider at least 5 molecules of the gas, and find the ratio that the weight of these 5 molecules of gas bears to the sum of the weights of the 4 molecules of nitrogen and 1 molecule of oxygen (air). This ratio is the specific gravity of the gas referred to air at the same temperature and pressure; thus,

	Calculated Specific Gravity	Actual Specific Gravity
CO,	$\frac{5\times28}{4(2\times14)+(2\times16)} = .972$	.967
CO_2,	$\frac{5\times44}{4(2\times14)+(2\times16)} = 1.528$	1.529
NH_3,	$\frac{5\times17}{4(2\times14)+(2\times16)} = .590$	.589
CH_4,	$\frac{5\times16}{4(2\times14)+(2\times16)} = .556$	.559
C_2H_4,	$\frac{5\times28}{4(2\times14)+(2\times16)} = .972$	.978

The difference between the calculated and the actual specific gravities of these gases is due to two causes: (1) Air always contains small quantities of carbon dioxide gas, ammonia gas, and moisture. (2) The exact proportion, by volume, of the nitrogen and oxygen gases forming air is (Art. 73) expressed by the ratio 79.1:20.9 instead of 4:1 as stated approximately above.

To calculate the density of air referred to hydrogen as a standard, we have

$$\frac{4(2\times14)+(2\times16)}{5(2\times1)} = 14.4.$$

That is to say, any given volume of air is 14.4 times heavier than the same volume of hydrogen gas at the same temperature and pressure. Dividing the density of any gas referred to hydrogen by 14.4 will give the specific gravity of the gas referred to air. For example, the density of carbon dioxide referred to hydrogen is 22 (Table 1) and

$\frac{22}{14.4}=1.5278$, which is the calculated specific gravity of carbon dioxide referred to air.

44. Percentage Composition by Weight.—The chemical formula of any substance—solid, liquid, or gas—expressing as it does the composition of the substance, makes it possible to calculate therefrom its percentage composition, either by weight or by volume. To do this, first find the molecular weight of the substance, which is the sum of the atomic weights of its constituents. Then the ratio of the atomic weights of any of the constituent atoms to the molecular weight of the substance, multiplied by 100 will give the percentage by weight of that constituent. For example, a molecule of water (H_2O) contains 2 atoms of hydrogen and 1 atom of oxygen, and its molecular weight is found thus,

Hydrogen,	2 atoms,	atomic weight,	$2\times1=\ 2$
Oxygen,	1 atom,	" "	$\underline{16}$
Water,		molecular weight,	18
Hydrogen,	percentage by weight,		$\frac{2}{18}\times100=11.1+\%$
Oxygen,	" " "		$\frac{16}{18}\times100=88.9-\%$

In like manner, the percentage composition, by weight, of carbon dioxide (CO_2), a molecule of which contains 1 atom of carbon and 2 atoms of oxygen, is as follows:

Carbon, 1 atom,	atomic weight,	12
Oxygen, 2 atoms	" "	$2\times16=\underline{32}$
Carbon dioxide,	molecular weight,	44
Carbon,	percentage by weight,	$\frac{12}{44}\times100=27.3-\%$
Oxygen,	" " "	$\frac{32}{44}\times100=72.7+\%$

In a similar manner, whenever the chemical *equation* expressing a reaction is known, it is possible to calculate the relative weights of the substances concerned in the reaction. For example, from equation 7, expressing the reaction that takes place in the complete combustion of methane (marsh gas) in air, it is possible to calculate the weight of air required to completely burn a given weight of this gas; also, the weights of carbon dioxide and water formed as a result of the combustion. To do this, we write again the equation, and underneath this the relative weight of each constituent; thus,

$$\begin{array}{lcccccc} & \mathrm{CH_4} + & 2\mathrm{O_2} + & 8\mathrm{N_2} = & \mathrm{CO_2} + & 2\mathrm{H_2O} + & 8\mathrm{N_2} \\ \text{Relative weight} & 16 & 64 & 224 & 44 & 36 & 224 \end{array}$$

The above relative weights are calculated by taking the sum of the atomic weights of the constituent atoms in each case, as just explained. The weights thus found represent the total relative weights of the several constituents concerned in this reaction. Since the oxygen and nitrogen in this equation together constitute the air, the relative weight of the air consumed is $64+224=288$. Hence 288 pounds of air are required to completely burn 16 pounds of methane, or the ratio is 18 pounds of air to 1 pound of gas. In like manner it is observed that the complete combustion of 16 pounds of methane produces 44 pounds of carbon dioxide gas and 36 pounds of water in the form of vapor; there remains also as a product of this combustion 224 pounds of nitrogen.

The ratio between the relative weights of any two constituents in this equation is always equal to the ratio of the actual weights of such constituents. For example, let it be required to find the weight of carbon dioxide gas produced by the complete combustion of, say, 100 pounds of methane. The ratio of the relative weights of these gases in this equation is 44:16, which may be written as a fraction, thus $\frac{44}{16}$; then, calling the required weight of carbon dioxide x, the ratio of the actual weights of these gases is $x:100$, or $\frac{x}{100}$, and

$$\frac{x}{100} = \frac{44}{16},$$

or

$$x = \frac{44}{16} \times 100 = 275 \text{ lb.}$$

In like manner the relative weights of any of the other constituents may be found from the ratio of their relative weights in the equation.

Example.—What weight of air will be consumed in the complete combustion of 150 pounds of methane or marsh gas?

Solution.—First write the chemical equation expressing the reaction that takes place when methane is completely burned in air, and underneath each constituent write its relative weight, as previously explained. Then, calling x the required weight of air, make the ratio of the actual weights equal to the ratio of the relative weights of these constituents; thus

$$\frac{x}{150} = \frac{288}{16};$$

and

$$x = \frac{288}{16} \times 150 = 2{,}700 \text{ lb.} \quad \textit{Ans.}$$

45. Percentage Composition by Volume.—It has been explained (Art. 31), as a deduction from Avogadro's law, that, with few exceptions, all gaseous molecules at the same temperature and pressure have the same volume. If we are careful then to write every chemical equation so as to express each constituent in *molecules*, the number of molecules of each constituent will represent its relative volume. For example, in equation 7, it is observed that

1 molecule of methane when completely burned in air yields 1 molecule of carbon dioxide gas and 2 molecules of water vapor, and 8 molecules of nitrogen, also, remain from the air; and this combustion required in all, approximately, $2+8=10$ molecules of air. Hence the complete combustion of this gas in air requires practically 10 volumes of air and produces 1 volume carbon dioxide gas, 2 volumes water vapor, and 8 volumes of nitrogen, making 11 volumes in all. There were before the combustion took place 1 volume of gas and 10 volumes of air; hence, in this case the reaction itself produced no change in volume, which is not true of every reaction.

The percentage by volume of any constituent of the products of a reaction is calculated from the ratio its molecular volume bears to the sum of the molecular volumes of all the constituents, in the same manner as described with reference to percentage by weight, Art. 44. For example, the complete combustion of methane or marsh gas in air, as expressed by equation 7, yields 1 molecule carbon dioxide, 2 molecules water vapor, and 8 molecules nitrogen, making 11 molecules in all. The percentage by volume of each of these several constituents is therefore as follows:

Carbon dioxide, percentage by volume,	$\frac{1}{11}\times 100=$	9.09+%
Water vapor, “ “ “	$\frac{2}{11}\times 100=$	18.18+%
Nitrogen, “ “ “	$\frac{8}{11}\times 100=$	72.73−%
	Total,	100.00%

As with respect to the relative weights, so likewise the relative volumes of any of the constituents may be found from the ratio of their molecular volumes, in the chemical equation expressing the reaction that takes place, remembering that the ratio of the molecular volumes of any two constituents is always equal to the ratio of their actual volumes. For example, let it be required to find the volume x, of nitrogen, remaining after the complete combustion of, say 100 cubic feet of methane or marsh gas. The ratio of the molecular volumes of these gases, in equation 7, is 8:1, or $\frac{8}{1}$, and the ratio of their actual volumes is x:100, or $\frac{x}{100}$; and since these ratios are always equal, we have

$$\frac{x}{100} = \frac{8}{1};$$

and

$$x = \frac{8}{1} \times 100 = 800 \text{ cu. ft., approximately.}$$

In like manner it may be found that the same volume of methane completely burned in air produces 100 cubic feet carbon dioxide, 200 cubic feet water vapor, and requires 1,000 cubic feet of air for the combustion.

46. Change of Volume Due to Chemical Reaction. Chemical reaction is sometimes accompanied by a change in the volume of the gases, the volume of the gases produced being greater or less than the volume of the gases entering the reaction, measured at the same temperature and pressure. This change of volume, therefore, is not due to the expansion or contraction of the gases owing to any change in their temperature (Art. 61) or pressure (Art. 63), which will be explained later. The change in volume due to chemical reaction has not thus far been explained by science; its effect will be better understood, however, if it is remembered that, in accordance with Avogadro's law (Art. 31), the volume of gaseous molecules, at the same temperature and pressure, is the same regardless of the number of atoms forming the molecule.

The equations expressing one or two simple reactions will make this clear. For example, 2 molecules of hydrogen and 1 molecule of oxygen in combination form but 2 molecules of water, according to the equation

$$2H_2+O_2=2H_2O$$

It is observed from this equation that 3 molecules of hydrogen and oxygen gases, representing 3 volumes, yield in combination but 2 molecules or volumes. This equation, like all other equations, is founded on experiment, which has shown that when 2 volumes of hydrogen and 1 volume of oxygen combine they form but 2 volumes of water vapor. This means that if 2 cubic feet of hydrogen are mixed with 1 cubic foot of oxygen, making 3 cubic feet of the mixed gases, and these gases are caused to unite, there will result from the reaction but 2 cubic feet of water vapor at the same temperature and pressure.

Or, again, if 2 cubic feet of ammonia gas be confined in a closed vessel and electric sparks are passed through the gas for some time, dissociation will take place, and there will be found in the tube 1 cubic foot of nitrogen mixed with 3 cubic feet of hydrogen, making 4 cubic feet of the mixed gases in place of the original 2 cubic feet of ammonia gas. This reaction is expressed by the following equation:

$$2NH_3=N_2+3H_2$$

It will be observed that in the complete combustion of methane in air, as expressed by equation 7, there is no change of volume due to the reaction, there being 11 volumes of gas and air before and 11 volumes of gas and vapor after the reaction.

47. Calculation of Change of Volume.—If the chemical equation expressing any reaction be so written that each substance is expressed as one or more *molecules*, the number of molecules of each gas or vapor will indicate its relative volume. These relative volumes may be written underneath each substance if desired. Thus the chemical equation expressing the reaction that takes place when carbon monoxide burns in air may be written as follows:

$$\begin{array}{lccccc} & 2CO + & O_2 + & 4N_2 = & 2CO_2 + & 4N_2. \quad . \quad . \quad (8) \\ \text{Relative volumes,} & 2 & 1 & 4 & 2 & 4 \end{array}$$

It is observed here that the 7 volumes before the reaction have been reduced to but 6 volumes after the reaction has taken place. The reduction of volume in this case is in the ratio of 7:6. If there had been 700 cubic feet of the mixed gas and air before explosion, there would be but 600 cubic feet of gases remaining after the explosion measured at the same temperature and pressure.

In a chemical equation the ratio of the relative volumes of any two gases is always equal to the ratio of their actual volumes. Thus in the above equation the relative volume ratio of air to carbon monoxide is 5:2. Suppose it is desired to know the volume x, of air, required to burn 150 cubic feet of this gas. The actual volume ratio is then x:150; and these two ratios being always equal may be written

$$\frac{x}{150} = \frac{5}{2}; \text{ or } x = 150 \times \frac{5}{2} = 375 \text{ cu. ft.}$$

Example.—How many cubic feet of gaseous products will result from the explosion of 350 cubic feet of carbon monoxide in air, measured at the same temperature and pressure?

Solution.—In this case, referring to the above equation, it is seen that the relative volume ratio of gases produced to those producing the reaction is 6:7; and, calling the required quantity of gaseous products x, the actual volume ratio is $x:350$. Hence,

$$\frac{x}{350}=\frac{6}{7}; \text{ or, } x=350\times\frac{6}{7}=300 \text{ cu. ft.} \quad \textit{Ans.}$$

48. Effect of Change of Volume.—The contraction of the volume that occurs in some chemical combinations of gases involves necessarily the simultaneous transformation of some of the latent heat (kinetic energy) of the gases into sensible heat (Art. 57), being similar in this respect to the effect produced when the gas is compressed by an external force. Heat is evolved, but not, however, as the result of an increase of pressure, the latter remaining constant. The development of heat accompanies a change of volume in either case, but when the change of volume is due to a chemical change the heat comes from internal sources, and when the change of volume is due to an external force the heat is due to the transformation of that force.

If the gases are confined, or if the *initial pressure* at the moment of the change is considered, there results a change of pressure owing to the expansion of the gas to fill the original space occupied. The reduction of pressure in this case is nearly in the ratio of the contraction of volume. In other words, the pressure ratio is nearly equal to the relative-volume ratio. The initial pressure due to the explosion of carbon monoxide is reduced from this cause in about the ratio of 6:7.

Owing to the heat evolved by the chemical change being absorbed by the gases the contraction of volume is adiabatic (Art. 64); the subsequent expansion is also adiabatic. Hence, calling the original volume of the gases v_1 and the contracted volume as shown by the chemical equation expressing the reaction v_2, and the original and final absolute pressures p_1 and p_2 respectively, the exact relation of these volumes and pressures is expressed by the formula

$$\frac{p_2}{p_1} = \left(\frac{v_2}{v_1}\right)^{.83} \qquad (9)$$

Formula 9 will be further explained and its application shown by example (Art. 64), after a study of heat in Chapter II.

EXAMINATION QUESTIONS

Specific Gravity

1. Calculate the weight of a block of coal measuring 3 ft. 4 in. long, 2 ft. 3 in. wide, and 16 inches thick, when the specific gravity of the coal is 1.4. *Ans.* 875 lb.

2. A piece of alloy is found to weigh exactly 5 pounds in the air, and when submerged in water its weight is but 4 lb. 6 oz., what is its specific gravity? *Ans.* 8.

3. To determine the specific gravity of a certain oil, a flask was first filled with pure water and its weight full of water was found to be 800 grains; the same flask was then filled with the oil and its weight when full of oil was 752 grains; what is the specific gravity of the oil? *Ans.* .94.

4. Find the weight of 250 cubic feet of carbon dioxide gas, whose specific gravity is 1.529 (Table 1), at a temperature of 32° F. and a barometric pressure of 30 inches.
Ans. 30.858+ lb.

5. A glass stopper weighs in the air 620 grains, in water 570 grains, and in a certain liquid only 530 grains; what is the specific gravity of the liquid? *Ans.* 1.8.

6. (*a*) Calculate the specific gravity of sulphureted hydrogen gas (H_2S). (*b*) What is its actual specific gravity as determined by experiment? *Ans.* (*a*) 1.1805; (*b*) 1.1912.

Chemistry

7. Calculate the percentage composition, by weight, of methane or marsh gas (CH_4). *Ans.* C, 75 per cent. H, 25 per cent.

8. What weight of oxygen gas will be required to completely burn 10 cubic feet of carbon monoxide gas, measured at a temperature of 32° F. and a barometric pressure of 30 inches? *Ans.* .446 + lb.

9. (*a*) Find the weight of 1 cubic foot of oxygen at 32° F. and 30 inches barometer. (*b*) What is the volume of the oxygen gas in the last example, at this temperature and pressure? *Ans.* (*a*) .0892 + lb. (*b*) 5 cu. ft.

10. (*a*) Write the chemical formula expressing the reaction that takes place when carbon monoxide gas burns in oxygen. (*b*) What volume of oxygen gas will be required to consume 10 cubic feet of carbon monoxide gas?

Ans. (*a*) $2CO + O_2 = 2CO_2$

(*b*) 5 cu. ft.

11. What volume of air will be consumed and what volumes of carbon dioxide and nitrogen produced in the complete combustion of 100 cubic feet of methane?

Ans. Air, 1,000 cu. ft.
CO_2, 100 " "
N_2, 800 " "

12. What is the percentage composition by volume of the gaseous products resulting from the combustion of carbon monoxide in air? *Ans.* CO_2, $33\frac{1}{3}$ per cent. N_2, $66\frac{2}{3}$ per cent.

CHAPTER II

HEAT AND ITS EFFECTS

49. As previously explained (Art. 27), the term *heat* describes a condition or state of matter that can be measured as energy is measured. It is assumed that this condition or state of matter is one of motion, and that the sensation imparted by heat is due to the rapid vibration of the molecules of the heated matter. This hypothesis is supported by the fact that heat may be converted into motion and motion into heat, and this exchange is always effected in a constant ratio by an exact numerical law that has been fully demonstrated by the careful and elaborate experiments of Joule and others.

50. Temperature.—A popular fallacy that is far from the scientific fact is to regard the temperature of a body as a measure of the heat it contains. Temperature depends both on the quantity of heat in the body and the capacity of that body for heat; it is thus a relative term and not an *absolute* unit of measure. Temperature is measured in degrees, which form the units of a thermometer scale. There are three common thermometer scales known as the Fahrenheit, Centigrade, and Reaumur scales. For the sake of comparison, the three scales are shown in Fig. 6, side by side. Each of these scales is graduated with reference to two fixed points, which present an invariable temperature and are readily obtainable. These are the temperature of *melting ice* and that of *boiling water* (sea level). The former or lower reference point registers on the three scales respectively 32° F., 0° C., and 0° R.; the latter or higher reference point registers likewise 212° F., 100° C., and

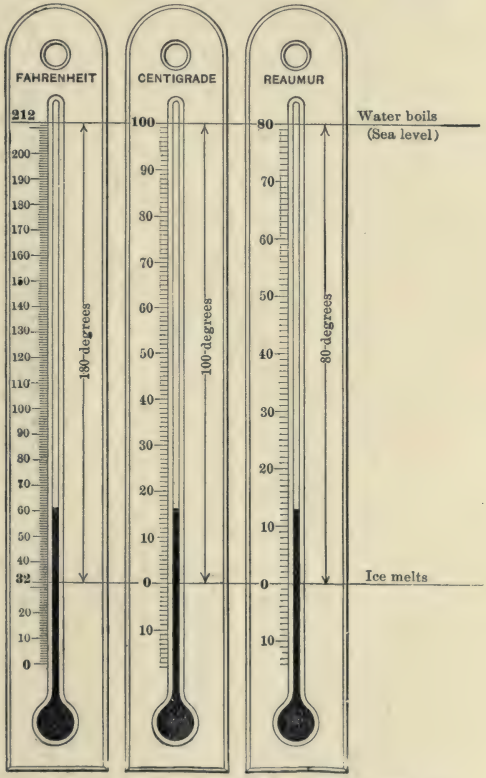

Fig. 6.—Comparison of Thermometer Scales

80° R. It will be observed that from this arbitrary marking of the scales 180 degrees of the Fahrenheit scale correspond to 100 degrees and 80 degrees respectively of the Centigrade and the Reaumur scales. The thermometer in common use consists of a fine capillary glass tube with a small bulb blown on the lower end. Mercury is introduced into this tube; and after boiling the mercury to expel all air from the mercury and tube, the upper end of the tube is sealed. Any change in temperature is indicated by the expansion or contraction of the mercury causing the column to rise or fall in the tube.

The following formulas will furnish a ready means of converting the readings of one scale into the corresponding readings of another scale, and will be understood without further explanation than to say the letters F, C, and R indicate the respective scale to which the reading is referred:

$$F = \tfrac{9}{5}C + 32; \quad \ldots \ldots \quad (10)$$

$$F = \tfrac{9}{4}R + 32; \quad \ldots \ldots \quad (11)$$

$$C = \tfrac{5}{9}(F - 32); \quad \ldots \ldots \quad (12)$$

$$R = \tfrac{4}{9}(F - 32); \quad \ldots \ldots \quad (13)$$

$$C = \tfrac{5}{4}R; \quad \ldots \ldots \quad (14)$$

$$R = \tfrac{4}{5}C. \quad \ldots \ldots \quad (15)$$

In using the above formulas it is important to notice that 32 is added and subtracted algebraically; that is to say, when the signs are like the quantities are added together, their sum taking the same sign; but when the signs are unlike the lesser quantity is subtracted from the greater, the difference taking the sign of the greater. Readings below zero have a minus (−) sign, and readings above zero a plus (+) sign. A few examples will show the use of the formulas.

Example 1.—Find the Centigrade reading corresponding to 50° F.

Solution.—Substituting the given Fahrenheit reading for F, in formula 12,

$$C = \tfrac{5}{9}(50 - 32) = 10° \text{ C.} \quad \textit{Ans.}$$

EXAMPLE 2.—Find the Reaumur reading corresponding to 23° F.

Solution.—Substituting the given Fahrenheit reading for F, in formula 13,

$$R = \tfrac{4}{9}(23-32) = -4° \text{ R.} \quad \textit{Ans.}$$

EXAMPLE 3.—Find the Fahrenheit reading corresponding to 12° C.

Solution.—Substituting the given Centigrade reading for C, in formula 10,

$$F = \tfrac{9}{5}12 + 32 = 53.6° \text{ F.} \quad \textit{Ans.}$$

51. Sources of Heat.—The great natural sources of heat are the sun, the interior of the earth, and the bodies of men and animals. The heat from all of these sources, however, is produced originally by the same causes that generate artificial heat. As a general proposition, the origin of all heat is *energy* in one form or another; the energy may be that due to chemical action or it may be mechanically developed, but both alike may be converted into heat. Whenever energy is absorbed or consumed without the production of mechanical work, heat is the result. A soft piece of iron may be made red hot by hammering; two pieces of smooth pine wood may be inflamed by rubbing them together; heated journals and cutting-tools for iron and stone furnish numerous other examples of the conversion of energy into heat.

52. Heat in Matter, Change of State.—It is now quite generally assumed that the particles of all matter are in a state of constant motion, and that this motion imparts the sensation described as heat and constitutes that condition of matter by virtue of which the quantity of heat contained may be measured. Bodies are described as being *cold* or *hot*, but these terms are only relative, depending on the heat capacity of the body, while the *quantity of heat* the body contains in any case is an exact amount that can be measured. It is assumed that no body or substance is wholly devoid of heat, but that all matter contains a certain amount, however small.

As will be explained shortly, different kinds of matter have different capacities for heat, and therefore require different amounts of heat to produce similar changes within themselves. Different substances pass from a solid to a liquid state, or from a liquid to a gaseous state, at different temperatures, though the pressure may remain the same. Heat and pressure are the principal agents producing such changes in the form of matter. The melting of ice at 32° F. and the vaporization of water at 212° F., or the melting of different metals and the vaporizing of different substances at numerous temperatures, illustrate the changes of form produced by heat.

53. **Transmission of Heat.**—Heat is transmitted from one body to another or passes from one body into another in any one of three different ways, by *radiation*, by *conduction*, or by *convection*. Heat is radiated from a body or source as light is radiated from a candle, in more or less straight lines and in every direction; radiant heat, like light, passes through a vacuum. All bodies thus radiate heat, but there is a *loss* of heat resulting in a fall in the temperature of the body when more heat is radiated than is received.

Conduction takes place when heat travels from one portion of a solid body to another, or from one body to another with which it is in contact. The rapidity of conduction depends on the kind of matter of which the body is formed, and the quantity of heat transferred depends further on the time.

Convection takes place only in fluids and is the carrying of heat from one part to another by the circulation of the fluid. Thus, the circulation of the water in a steam-boiler or that of the heated air in a room distributes the heat throughout the boiler or the room, as the case may be.

54. Measurement of Heat, Heat units.—The measurement of heat, like the weighing of an atom or estimating the volume of an atom or molecule, is and can be only relative to some adopted unit. There are three thermal or heat units in common use all of which are referred to water at its maximum density (4° C. = 39.2°F.); they are as follows:

The *British thermal unit* (B.T.U.) is a quantity of heat that will raise the temperature of 1 pound of water 1° F. at its point of maximum density.

The *French unit* or *calorie* is a quantity of heat that will raise the temperature of 1 kilogram of water 1° C. at its point of maximum density.

The *pound-calorie* is a quantity of heat that will raise the temperature of 1 pound of water 1° C. at its point of maximum density.

$$1 \text{ British thermal unit} = \begin{cases} .252 \text{ calorie, or} \\ 5/9 \text{ pound-calorie.} \end{cases}$$

$$1 \text{ calorie} = \begin{cases} 3.9683 \text{ B.T.U., or} \\ 2.2046 \text{ pound-calories.} \end{cases}$$

$$1 \text{ pound-calorie} = \begin{cases} 9/5 \text{ B.T.U., or} \\ .4536 \text{ calorie.} \end{cases}$$

The amount of heat given out from a body is expressed in terms of one of the above units. This is determined practically by ascertaining, by careful experiment with properly constructed apparatus, the exact rise in temperature of a given weight of water at or near the temperature of its maximum density. The number of degrees (Fahr.) rise in temperature of the water multiplied by its weight (lb.) will be the number of B.T.U. given out by the body. The same quantity of heat will be required to again raise the body to its original temperature.

55. Mechanical Equivalent of Heat.—The conversion of heat into energy and energy into heat, which always occurs in an exact numerical ratio (Art. 49) has led to the expression *mechanical equivalent* of heat, by which is meant the amount of *work* (foot-pounds) that is equivalent to a single *heat unit* (B.T.U.). Experiment has established this value as

1 B.T.U. = 778 foot-pounds;
or 1 foot-pound = .001285 B.T.U.;
1 horsepower = 2,545 B.T.U. per hour, nearly.

The mechanical equivalent of heat makes it possible to determine the amount of heat that will be absorbed in the performance of any given work.

56. Heat Capacity, Specific Heat.—Different kinds of matter have different capacities for heat. This is shown by the fact that when the same quantity of heat is imparted to equal weights of different substances, a different rise in temperature is produced in each substance; and, again, the same fall in the temperature of different substances causes them to give out different quantities of heat. Thus a substance will heat quicker and its temperature rise higher for the same quantity of heat imparted to it, as its heat capacity is smaller; and *vice versa* it will heat slower and experience a less rise of temperature for the same quantity of heat imparted, as its heat capacity is larger.

The heat capacity of a body or substance is measured by the number of heat units required to raise the temperature of a unit weight of the substance one degree. If the heat is estimated in B.T.U. the unit weight is 1 pound and the rise in temperature is 1° F.; or, if pound-calorie is used, the unit weight is still 1 pound, but the rise in temperature is 1° C. When the heat is estimated in calories the unit weight is 1 kilogram, and the rise in temperature 1° C. This quantity of heat is called the *specific heat* of the substance.

The specific heat of a substance may be defined as the ratio of the quantity of heat required to raise the temperature of a given weight of that substance one degree, to the quantity of heat required to produce the same rise in temperature in an equal weight of water at its maximum density. It is important to notice that the specific heat of any substance—solid, liquid, or gas—is the number of thermal units required to raise the temperature of a unit weight of that substance one degree.

The specific heats and specific gravities of the more common mine gases, aqueous vapor, and air are given in the following table:

TABLE 4

SPECIFIC HEATS OF AIR, MINE GASES, AND VAPORS (WATER = 1)

Gas or Vapor	Symbol	Equal Weights		Equal Volumes	Specific Gravity, Air = 1
		Constant Pressure	Constant Volume	Constant Pressure	
Air.	. . . .	.2374	.1689	.2374	1.
Oxygen.	O_2	.2175	.1548	.2405	1.1056
Nitrogen.	N_2	.2438	.1735	.2368	.9713
Hydrogen.	H_2	3.4090	2.4260	.2361	.06926
Methane.	CH_4	.5929	.4219	.3314	.559
Carbon monoxide. . .	CO	.2450	.1743	.2369	.967
Carbon dioxide.	CO_2	.2163	.1539	.3307	1.529
Hydrogen sulphide .	H_2S	.2432	.1731	.2897	1.1912
Olefiant gas.	C_2H_4	.4040	.2875	.3951	.978
Aqueous vapor.	H_2O	.4805	.3419	.2996	.6235
Nitrous oxide.	N_2O	.2262	.1610	.3450	1.525

The specific heats given in Table 4 are all referred to water as unity. The specific heat of a gas varies according as the gas is allowed to expand (constant pressure) or is confined in a given space (constant volume). When the gas is allowed to expand, its specific heat is always higher than when it is confined, owing to the absorption of heat when the gas expands. These two conditions are referred to as *specific heat under constant pressure*, and *specific heat under constant volume*. Taking the quantity of heat necessary to raise the temperature of one pound of water at its maximum density one degree Fahrenheit as unity, the first two columns of the table show the quantity of heat (B.T.U.) that will produce the same rise of temperature in an equal weight of each of the several mine gases for ordinary temperatures. The third column shows likewise the quantity of heat (B.T.U.) necessary to produce the same rise of temperature in a volume of each gas, equal to the volume of a pound of air.

The specific heat of gases is not always constant, but varies with the temperature of the gas, increasing slowly as the temperature rises. It is stated by some reliable authorities that the specific heat of carbon dioxide gas at a temperature of 1,200° F. is practically double that given in the table. This gas is probably more sensitive in this respect than any of the other gases. The specific heat of steam or aqueous vapor increases very rapidly above 212° F. The specific heats of the simple gases and of air do not increase as rapidly at the higher temperatures. The specific heats given in the first column of the table for equal weights and constant pressure are those determined by actual experiment and given by the most reliable authorities; they are mostly based on the experiments of Regnault. The specific heats given in the second column of the table for equal weights and constant volume have been derived by calculation from the specific heats in the first column for constant pressure by dividing the latter by 1.405, which is the most generally accepted ratio fcr the specific heat of a gas at *constant pressure* to the specific heat at *constant volume.* The figures given in the third column of the table express the heat capacities of equal volumes of gas and air at constant pressure instead of equal weights. These are not, therefore, strictly speaking, specific heats, although generally so called. The values in this column have been derived by calculation by multiplying the specific heats in the first column by the specific gravity of the gas.

57. Sensible Heat; Latent Heat.—All heat imparted to bodies does not necessarily produce a rise in the temperature of the body. Heat imparted to a body causes a rise in its temperature till a point is reached at which any further addition of heat is absorbed in producing a molecular change that results in altering the form of the body, as explained (Art. 52). Heat that produces a rise in temperature is called *sensible heat,* while that absorbed in producing a change in the body is called *latent heat.* Latent heat is again given out and becomes sensible when the body passes back to its original form or state. The melting of ice or the vaporization of water is accompanied by an absorption of the sensible heat of the surrounding air, whereby the air is cooled. On the other hand, the condensation of steam or the freezing of water is accompanied by a giving out of the latent heat of the steam and the water that becomes at once sensible in the surrounding air, which is heated thereby. It is this transfer of heat from water to air and from air to water that causes the temperature of the atmosphere in the Spring and Fall to apparently become stationary so often at the point of freezing (32° F.).

For the present purpose it is sufficient to consider the quantity of heat (B.T.U.) absorbed or rendered latent by the melting of one pound of ice at 32° F. to water at 32° F. and the evaporation of a pound of water at 212° F. to steam at 212° F.; or, in other words, the latent heat of fusion, from and at 32° F., and the latent heat of vaporization, from and at 212° F., the former being 144 B.T.U. and the latter 966 B.T.U. The total heat absorbed, therefore, when a pound of ice at 32° F. is converted into steam at 212° F. is, approximately, as follows:

Latent heat of fusion of ice, from and at 32° F.	144 B.T.U.
Sensible heat to raise temperature of 1 lb. of water from 32° F. to 212° F.	180 “
Latent heat of vaporization of steam, from and at 212° F.	966 “
Total heat per lb., from ice at 32° F. to steam at 212° F.	1,290 B.T.U.

It may be necessary in some instances, in connection with the conditions incident to mine explosions, to calculate the heat of formation of steam (water vapor) at temperatures higher than 212° F., in which case the formula of Regnault may be used. This formula gives the number of B.T.U. necessary to convert one pound of water at 32° F into steam at any temperature t; thus

$$B.T.U. = 1{,}081.4 + .305\,t \tag{16}$$

Example.—Calculate the total quantity of heat absorbed in converting 10 pounds of water, at a temperature of 50° F., into steam at 400° F.

Solution.—First find the total heat required to convert 1 pound water at 32° F. into steam at 400° F., by substituting the given value for t in formula 16; thus

$$B.T.U. = 1{,}081.4 + .305 \times 400 = 1{,}203 + \text{B.T.U.}$$

The required heat for 10 pounds of water at 50° F. is then

$$10(1{,}203 + 32 - 50) = 11{,}850 \text{ B.T.U.} \quad \textit{Ans.}$$

58. Evaporation, Boiling.—The term "evaporation" expresses what takes place at the free surface of a liquid when it vaporizes or passes from the liquid to the gaseous state; the boiling or ebullition of a liquid describes the formation of vapor rapidly throughout the mass of the liquid. Evaporation takes place from water, and even from ice and snow, at all temperatures, but the boiling-point of pure water for the same atmospheric pressure is a fixed point (212° F; pressure, 14.7 lb. per sq. in.). Wet boards steaming in the air, or wet clothes drying in the wind, are examples of evaporation taking place at all temperatures.

Evaporation at any temperature is always accompanied by an absorption of heat, which cools the air where the evaporation is taking place. In a mine the air-current is thus cooled by the evaporation and warmed by the condensation of the moisture, which occurs at certain points in the airway. These phenomena produce important effects in equalizing the temperature of the air throughout the mine. The same action going on in a wet furnace shaft transfers the heat from the bottom to the upper portion of the shaft, and tends to equalize the temperature throughout the shaft by the evaporation of the water in the lower and hotter portion and its condensation again in the upper and cooler portion.

59. Expansion.—An important effect of heat upon bodies is the expansion that it causes in the volume of the body. There is a considerable variation in the amount of expansion of different solids and liquids, but all gases and air expand and contract according to the same law. The law of the expansion of gases was first investigated by Gay-Lussac and Charles, and is known as Gay-Lussac's or Charles' law. This law established the fact that all gases and air have the same coefficient of expansion, or, in other words, expand alike for the same change in temperature, and this was found to be true for all pressures. The amount of this expansion was determined with accuracy later by Regnault, and found to be 1/273 of the volume of the gas at 0° C. for each degree rise in temperature, of the Centigrade scale. This is taken to correspond to 1/460 of the volume of the gas at 0° F. for each degree rise in temperature, of the Fahrenheit scale.

60. Absolute Zero, Absolute Temperature.—It was the investigation of the law of the expansion of air and gases by heat, that gave rise to the determination of what is now known as the *absolute zero* of the thermometer scale. This is about 273.3 degrees below zero on the Centigrade scale ($-273.3°$ C.), or 460 degrees below zero on the Fahrenheit scale ($-460°$ F.). This point of the thermometric scale is merely a convenient zero point of a scale whose degrees of temperature will then be always proportional to the corresponding volumes of air or gas. In other words, from this point as zero the volume of gas or air increases in proportion to the temperature. Temperature reckoned from this point as zero has been called *absolute temperature.*

The absolute temperature corresponding to any temperature of the common scales is found by adding algebraically

273 to any common temperature of the Centigrade scale, or 460 to any common temperature of the Fahrenheit scale, always regarding temperatures below zero as minus, and those above zero as plus; thus:

25° C. common temp. is 273 + 25 = 298° C. absolute temp.
−10° C. " " " 273 − 10 = 263° C. " "
60° F. " " " 460 + 60 = 520° F. " "
−40° F. " " " 460 − 40 = 420° F. " "

61. Relation of the Absolute Temperature and Volume of Air and Gases.—Considering a given weight of air or gas at a constant pressure the volume is always proportional to the absolute temperature of the air or gas. Fig. 7 will assist to make more clear the relation that exists between the absolute temperature and the volume of gases. On the left of the figure is a vertical scale of temperatures, expressed both as common and absolute temperatures. From this vertical line is laid off by ordinates the corresponding volumes of air or gas, for any constant pressure. For the sake of convenience only, a volume of 460 cubic feet of gas at 0° F. is assumed, and its expanded or compressed volume is shown at different points of the scale. It will be observed that the volume of this body of gas always corresponds to its absolute temperature. Since the gas expands and contracts, according to **Gay-Lussac's** or **Charles'** law—1/460 of its volume at 0° F. for each degree rise or fall in temperature of the Fahrenheit scale—it would evidently contract to nothing at the absolute zero, if the gas maintained the same rate of contraction at these lower temperatures. It may be assumed, however, that while Gay-Lussac's law expresses with sufficient accuracy for all practical purposes the rate of expansion and contraction of gases due to their temperature for all ordinary temperatures, yet there has been observed at low temperatures sufficient variation from this law to warrant the belief that the curve of volumes becomes

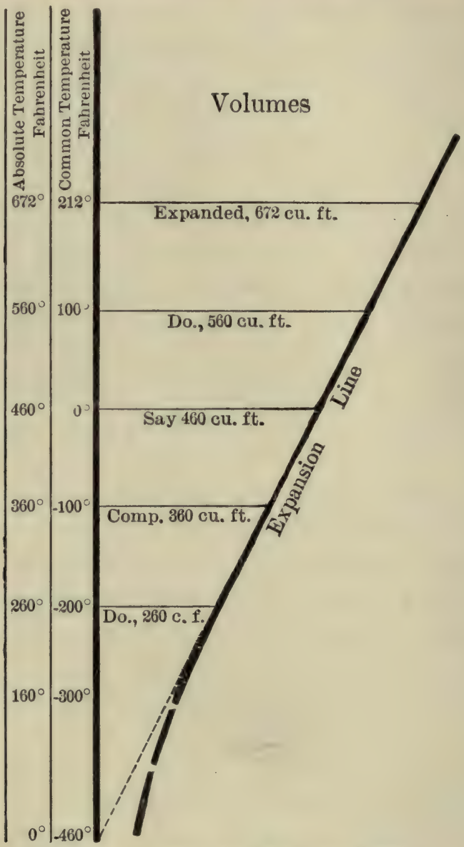

FIG. 7.—Expansion of Air and Gases

asymptote to the vertical at a lower temperature than it is possible to reach, where further contraction ceases.

The law of the expansion and contraction of air and gases, due to a change in temperature, like many other laws in ventilation, is expressed more concisely and clearly by ratios; thus:

RULE.—*For a constant pressure the volume ratio of any air or gas is always equal to the absolute-temperature ratio.*

Calling any two volumes of the same weight of air or gas, under a constant pressure, v_1 and v_2, and their corresponding absolute temperatures, T_1 and T_2, this rule is expressed by the formula

$$\frac{v_2}{v_1}=\frac{T_2}{T_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

EXAMPLE.—A volume of 10,000 cubic feet of air per minute is passing into a mine at a temperature of 10° F.; calculate the expanded volume of this air-current when it has reached the return airway where the temperature is 70° F.

Solution.—Calling the required volume x and writing the volume ratio equal to the absolute-temperature ratio, as expressed by formula 17,

$$\frac{x}{10{,}000}=\frac{460+70}{460+10}=\frac{530}{470};$$

and $$x=10{,}000\times\frac{53}{47}=11{,}276+\text{cu. ft. per min.} \quad \textit{Ans.}$$

The above relation of temperature and volume considers the air or gas as free to expand under the influence of the heat absorbed, the pressure remaining constant; if the air or gas is confined, however, any change in temperature is accompanied with a corresponding change in pressure.

62. Relation of the Absolute Temperature and Pressure of Air and Gases.—Considering a given weight of air or gas having a constant volume, the pressure or tension is always proportional to the absolute temperature, giving the following:

RULE.—*For a constant volume the pressure ratio of any air or gas is always equal to the absolute-temperature ratio.*

Calling any two pressures of the same weight of air or gas having a constant volume, p_1 and p_2 respectively, and their corresponding absolute temperatures, T_1 and T_2, this rule is expressed by the formula

$$\frac{p_2}{p_1}=\frac{T_2}{T_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

The pressure referred to in this rule is the pressure above a vacuum, or the absolute or total pressure supported by the gas and which is always equal to the tension of the gas.

Example.—Assuming an original atmospheric pressure (sea level) of 14.7 pounds per square inch, supported by a body of firedamp (marsh gas and air) and an original temperature of 60° F., find the initial pressure, or the pressure at the moment of explosion, when the temperature has increased to 5,840° F. (Art. 69), there being no change of volume due to the chemical reaction in this case (Art. 46).

Solution.—Calling the required pressure x and writing the pressure ratio equal to the absolute-temperature ratio, as expressed by formula 18,

$$\frac{x}{14.7}=\frac{460+5{,}840}{460+60}=\frac{6{,}300}{520};$$

and $$x=14.7\times\frac{315}{26}=178+\text{ lb. per sq. in.} \quad \textit{Ans.}$$

63. Relation of the Volume and Pressure of Air and Gases.—Considering a given weight of air or gas, any change in the volume is accompanied either with a change in the pressure or tension of the gas, or a change in the temperature (Art. 61), or a change both in the pressure and temperature. To determine these changes it is necessary to consider what caused the change of volume. Heat imparted to a free body of air or gas causes it to expand, or if heat be abstracted contraction takes place. Again, removing the pressure supported by a body of air or gas causes it to expand, or if the pressure be increased (compression) contraction takes place. But the expansion of air or gases increases their heat capacity, while compression decreases the same, as is evident by comparing the specific heats of equal weights of air and gases for constant pressure and volume in Table 4. This change of heat capacity causes the latent heat to be given out as sensible heat and the temperature to rise when air or gas is compressed; but when expansion occurs sensible heat is absorbed, becomes latent, and the temperature falls. Thus compression heats while expansion cools a body of air or gas, and this change of temperature complicates the relation between the *volume* and *pressure* of air and gases.

Assuming, however, that sufficient heat is added artificially during the expansion and abstracted during the compression of the air or gas to maintain the temperature constant, the pressure or tension will then vary, according to **Boyle's** or **Mariotte's law,** inversely as the volume, giving the following:

RULE.—*For a constant temperature, the volume ratio of any air or gas is always equal to the inverse pressure ratio.*

Calling any two volumes of the same weight of air or gas, at a constant temperature, v_1 and v_2, and their corresponding absolute pressures, p_1 and p_2, this rule is expressed by the formula

$$\frac{v_2}{v_1}=\frac{p_1}{p_2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

This formula may be applied in practically every case in mine ventilation where a change in volume occurs owing to a change in pressure, because the change of pressure is gradual and so slight that the consequent heating or cooling of the air may be ignored without appreciable error.

Example.—Assuming that an air-space of, say 100,000 cubic feet, in the abandoned workings of a mine, is filled with a dangerous mixture of air and gas when the barometric pressure is 30 inches of mercury; what volume of this gas-laden air will be thrown out upon the airways by a rapid fall of the barometer to 29.2 inches?

Solution.—In this case, calling the expanded volume of gas and air x, and writing the volume ratio equal to the inverse pressure ratio, as expressed by formula 19,

$$\frac{x}{100{,}000}=\frac{30}{29.2};$$

and

$$x=100{,}000\times\frac{30}{29.2}=102{,}740+\text{cu. ft.}$$

The quantity of air and gas thrown off on the airway will therefore be 102,740 − 100,000 = 2,740 cu. ft. *Ans.*

64. Adiabatic Expansion and Compression of Air and Gases.—When air or gas expands or is compressed without the addition or loss of heat, the following formulas express the relations that obtain severally between the volume, pressure, and temperature. These formulas are useful in numerous instances, but require the use of logarithms.

Volume and Temperature	Temperature and Pressure	Volume and Pressure
$\frac{v_2}{v_1}=\left(\frac{T_1}{T_2}\right)^{2.469}$	$\frac{T_2}{T_1}=\left(\frac{p_2}{p_1}\right)^{.288}$	$\frac{v_2}{v_1}=\left(\frac{p_1}{p_2}\right)^{.7117}$
$\frac{T_2}{T_1}=\left(\frac{v_1}{v_2}\right)^{.405}$	$\frac{p_2}{p_1}=\left(\frac{T_2}{T_1}\right)^{3.469}$	$\frac{p_2}{p_1}=\left(\frac{v_1}{v_2}\right)^{1.405}$

An interesting case of adiabatic expansion occurs as the result of the reduction of volume due to chemical change explained in article 46. To ascertain whether a reduction of volume takes place in any given case it is necessary to write the chemical equation expressing the reaction, and the relative volumes of the several gases or vapors, as explained in article 47. Such a contraction of volume is accompanied with an evolution of heat (Art. 48), the same as though the air had been compressed. The heat thus evolved causes a slight expansion, or rather reduces the amount of contraction that would otherwise occur in the volume of the gaseous products of the reaction, making the volume ratio $\frac{v_2}{v_1}$, in this case $\left(\frac{v_2}{v_1}\right)^{.59}$, and the final pressure ratio is then as given by equation (9) (Art. 48):

$$\frac{p_2}{p_1}=\left(\frac{v_2}{v_1}\right)^{.59\times1.405}=\left(\frac{v_2}{v_1}\right)^{.83}$$

EXAMPLE.—Assuming an original atmospheric pressure of 14.7 pounds per square inch (sea level) and a temperature of 60° F. in the mine, find the initial pressure due to the explosion of a body of carbon monoxide and air, at its most explosive point, or when the mixture consists of 2 volumes of the gas to 5 volumes of air, as shown by formula (8) (Art. 47), the temperature at the moment of explosion being 7,405° F. (Art. 69).

Solution.—The first step is to find the increase of pressure due to the increase of the temperature from 60° to 7,405° F., by substituting the given values in formula (18); thus, calling the resulting pressure x,

$$\frac{x}{14.7}=\frac{460+7{,}405}{460+60}=\frac{7{,}865}{520}=\frac{121}{8};$$

and

$$x=14.7\times\frac{121}{8}=222+\text{ lb. per sq. in.}$$

The second step is to find the reduced pressure that is the result of the change in volume due to the chemical reaction (Art. 48). To do this, again call the required pressure $p_2=x$ and substitute the value found above $p_1=222$, and the volume ratio determined by formula (8) (Art. 47), $\frac{v_2}{v_1}=\frac{6}{7}$, in formula (9); thus,

$$\frac{x}{222}=\left(\frac{6}{7}\right)^{.83};$$

and

$$x=222\times\left(\frac{6}{7}\right)^{.83}=195+\text{ lb. per sq. in. } \textit{Ans.}$$

COMBUSTION

65. In a broad sense combustion is any chemical reaction accompanied with the evolution of heat, and often with the production of light or flame or both. Combustion always involves at least two substances, one of which is the *combustible* and the other the *supporter of the combustion,* the latter being generally a gas. The reaction that takes place between these two substances is due to the stronger affinity that exists under certain conditions of temperature, between certain atoms of the combustible for certain other atoms of the substance supporting the combustion. In some cases it requires but a slight increase in temperature or a sudden jar or shock to start the reaction. The resulting combustion may be slow or rapid. Slow combustion produces heat or light, or both, while a more rapid combustion may be attended with heat or flame or both of these. When the combustion is the result of natural causes only it is called *spontaneous combustion.* This form of combustion will be considered in connection with the subject of *gob fires.*

66. **Oxidation** is that form of combustion in which the action is supported by oxygen or air. This includes all the more familiar forms of combustion, both slow and rapid. Most of the elements have an affinity for oxygen, which explains why that element enters most compounds. Oxygen is the most active element in producing chemical changes and forming new compounds. A large number of substances oxidize when exposed to the air; in other cases the application of heat is necessary to bring about this change, and in many instances the presence of moisture is necessary to or greatly assists the reaction. The corrosion of iron and other metals commonly known as

rusting, the decomposition of carbonaceous matter, the smoldering of gob fires, as well as the more rapid burning of coal on the grate, the explosion of gas or powder, etc., are all familiar forms of oxidation. The burning of hydrogen or phosphorus in chlorine are less familiar forms of combustion; these are not, however, examples of oxidation.

67. The **products of a combustion** are of two kinds—the resulting gases and vapors known as the *gaseous products* and the solid residue known as the *ash.* Some of the gaseous products are condensed to liquids on cooling. The explosion of ordinary black blasting powder, under the varying conditions of mining, gives a wide variation in the products of the explosion and makes it impossible to express correctly in a single equation the exact reactions taking place at different times under different conditions. The extensive series of experiments undertaken by the British War Department and carried out by Professor Abel, chemist of the War Department, and Captain Noble, has shown that when a charge of gunpowder is exploded in a closed vessel, the fused solid products of the explosion occupy practically one-third of the space filled by the original powder and the gaseous products the remaining two-thirds; and that the volume of the gaseous products measured at 32° F., barometer 29.92 inches, is 280 times the volume of the original powder, and being crowded into a space equal to two-thirds of the original volume of the powder, is equivalent to $280 \div \frac{2}{3} = 420$ volumes filling the entire space occupied by the powder. The temperature resulting from the reaction being 6,100° F., the confined gases represent $420\left(\frac{460+6,100}{460+32}\right)=5,600$ expansions, which at sea level corresponds to a pressure of $14.7 \times 5,600 \div 2,000 =$ say 40 tons per sq. in.

The chemical equation expressing, approximately, the reaction for gunpowder having the following general composition: Nitre, 75 per cent.; carbon, 12.5 per cent.; sulphur, 12.5 per cent., may be written as follows:

$$\underbrace{\mathrm{80KNO_3+56C_2+21S_2}}_{\text{Powder}}=\underbrace{\mathrm{24K_2CO_3+4K_2SO_4+12K_2S+13S_2}}_{\text{Solid products}}$$

$$\underbrace{\mathrm{+40N_2+64CO_2+24CO.}}_{\text{Gaseous products}}$$

The volume of the solid products of this reaction is about one-third of the original volume of the powder.

The products of the combustion of **nitroglycerin** are wholly gaseous. Bloxam gives the following analysis of these products: Carbon dioxide (CO_2), 37.2 per cent.; nitrous oxide (N_2O), 6.2 per cent.; nitrogen (N_2), 12.6 per cent.; and water vapor (H_2O), 44 per cent. The reaction that takes place at the moment of explosion may be expressed as follows:

$$\mathrm{2C_3H_5(NO_3)_3=6CO_2+N_2O+2N_2+5H_2O.}$$

The products of the combustion of **guncotton** in a closed space are practically all gaseous, there being but 1.85 per cent. of solid residue at the most in a good quality of the explosive. The explosion may be expressed in a typical way by the equation

$$\mathrm{4C_{12}H_{14}O_4(NO_3)_6=24CO+16CO_2+8CH_4+10NO_2+7N_2+12H_2O.}$$

The explosion of a known weight of guncotton in a closed vessel has shown the heat of the combustion to be 1,928 B.T.U. per pound of the explosive. The temperature of the explosion, computed on the basis of the above formula, is therefore 6,768° F. (Art. 69).

68. Heat of Combustion.—The results of numerous careful experiments have proved that a unit weight of any given combustible always produces by its combustion the same quantity of heat, provided the combustion each time attains the same degree of oxidation, so that it is represented by the same reaction. This makes it possible to determine with much accuracy the heating value or calorific power of different combustibles. The values determined by the experiments of Favre and Silbermann are generally conceded to be the most reliable, and are given in the following table as B.T.U. per pound of combustible burning in oxygen.

TABLE 5

HEAT OF COMBUSTION OF SUBSTANCES BURNING IN OXYGEN

Combustible	B.T.U. per Pound of Combustible	Authority
Hydrogen to water at 32° F.	62,032	Favre and Silbermann
" to steam at 212° F	51,717	"
Carbon to carbon dioxide at 60° F.	14,544	"
" to carbon monoxide.	4,451	"
Carbon monoxide to carbon dioxide.	4,325	"
Methane to carbon dioxide and water at 32° F.	23,513	"
Olefiant gas to carbon dioxide and water at 32° F.	21,344	"
Sulphur.	3,996	"
Coke, average quality	12,600	"
Wood (dry), average.	7,245	"
" (wet), average	5,580	"
Coal (anthracite).	12,350	Average of many tests
" (bituminous).	11,930	

The conditions under which the combustion of a substance takes place determine both the reaction and the resulting products and therefore the heat of the combustion. For the same reaction, however, the amount of heat developed, or the *heat of the combustion*, is constant.

69. Temperature of Combustion.—The temperature of any combustion will always depend on numerous factors and conditions. Unlike the *heat* of the combustion the temperature developed is not constant, even for the same reaction, but depends largely on the rapidity of the combustion. If the combustion be slow, much of the heat developed is lost by radiation and the temperature is correspondingly low. For example, the burning of a pound of carbon to carbon dioxide of a given temperature will always produce the same quantity of heat (Table 5), whether the combustion be slow or rapid; but if the combustion be slow, as in the slow oxidation of fine coal in the gob, much of the heat is radiated and lost and a low temperature results; while in the case of a dust explosion in a mine the burning with explosive rapidity of the same weight of fine coal dust suspended in the mine air produces a very high temperature, approaching and possibly attaining the theoretical limit. The theoretical temperature of a combustion therefore possesses a practical value in mining, because it suggests the possibilities of the situation.

The theoretical temperature of any combustion may be calculated by first writing the chemical equation expressing the reaction that takes place. The relative weight of each of the products of the combustion is then calculated for a unit weight of the combustible, by writing the molecular weights of the combustible and the several products of the combustion, and dividing each of the latter by the molecular weight of the combustible. Then multiply the relative weight of each of the products of the combustion by its specific heat (Table 4), using the values for constant pressure if the gases are free to expand, or for constant volume if they are confined. The sum of the several products thus obtained will be the amount of heat (B.T.U.), per pound of combustible, required to raise the temperature of the products of the combustion 1° F. Finally divide the heat of this combustion per pound of the combustible (Table 5) by the heat required to raise the products of the combustion 1° F., and the quotient will be the rise in temperature due to the combustion (deg. Fahr.). Adding this to the original temperature will give the temperature resulting from the combustion. The following example will serve as an illustration in mine ventilation.

Example.—Let it be required to calculate the initial temperature resulting from the explosion of a body of firedamp (marsh gas and air), at its most explosive point or when the combustion is complete, as represented by equation 7 (Art. 42). Find also the number of atmospheres produced by the explosion, or the number of expansions in the gaseous products resulting therefrom.

Solution.—First write the equation expressing the reaction that takes place when methane (marsh gas) burns to carbon dioxide and water, and underneath each substance write its molecular weight and its relative weight and volume, reducing each to a unit weight of the combustible; thus:

	$CH_4 +$	$2O_2 +$	$8N_2 =$	$CO_2 +$	$2H_2O +$	$8N_2$
Molecular weight.........	16	64	224	44	36	224
Relative weight..........	1	4	14	$\frac{11}{4}$	$\frac{9}{4}$	14
Relative volume..........	1	2	8	1	2	8

The relative weight of each of the products of this reaction is then multiplied by its specific heat to obtain the heat required to raise its temperature 1° F. The sum of these quantities of heat in the last column below gives the total heat per pound of combustible required to raise the temperature of the products of the combustion 1° F. Thus:

Gaseous Products	Specific Heats, Constant Volume	Relative Weights	Heat Required to Raise Temperature 1° F.
CO_2..............	.1539 B.T.U.	11/4	.423225 B.T.U.
H_2O.............	.3419 "	9/4	.769275 "
N_2...............	.1735 "	14	2.429000 "
Total..................................			3.621500 B.T.U.

The total heat produced when one pound of methane or marsh gas burns to carbon dioxide and water at 32° F. (Table 5) is 23,513 B.T.U. From this is subtracted the heat absorbed in converting water at 32° F. into steam at 212° F., which is $180+966=1{,}146$ B.T.U. for each pound of water (Art. 57); and in this case for $9/4=2\frac{1}{4}$ pounds there is absorbed $1{,}146\times 2\frac{1}{4}=2{,}578$ B.T.U., leaving $23{,}513-2{,}578=20{,}935$ B.T.U. as the net heat produced per pound of combustible. But 3.6215 B.T.U. are required to produce a rise of 1° F., and the total rise in temperature is then

$$\text{Total rise in temperature}=\frac{20{,}935}{3.6215}=5{,}780^\circ\text{ F.}$$

Assuming the original temperature of the gas as 60° F., the initial temperature resulting from the combustion will be $60+5{,}780=5{,}840^\circ$ F. *Ans.*

In like manner the initial temperature produced when carbon monoxide burns in air, producing carbon dioxide and nitrogen, may be calculated and is found to be 7,405° F.; showing that this combustion, which is what commonly takes place in the recoil or the return flame of a mine explosion, produces a much higher temperature than that produced by the explosion of methane (marsh gas).

The possible expansion of volume due to any increase of temperature is shown by the ratio of the absolute temperatures; the volume ratio of the gas being equal to the absolute-temperature ratio (Art. 61).

In the foregoing example, assuming an original temperature of 0° F., the final temperature would be 5,780° F. Then, comparing the expanded volume of the gas at this temperature with the volume of the gas at 0° F., the volume ratio or the number of expansions in the explosion of methane (marsh gas) above 0° F. is

Number of atmospheres, explosion of CH_4 above 0° F.,

$$\frac{460+5{,}780}{460}=13.56,\text{ say 14 atmospheres.}\quad \textit{Ans.}$$

In each of the above cases the temperature found is the *initial* temperature due to the chemical reaction and the heat of compression of the gases, and was obtained by taking the specific heats of the gases for *constant volume.* To find the temperature due to the chemical heat only, the specific heats of the gases for *constant pressure* must be taken, or the rise in temperature for constant volume divided by 1.405 will give the rise for constant pressure. The former considers the chemical heat and the heat of compression as sensible heat, which is true at the initial moment of explosion or whenever the gases are confined; the latter considers the chemical heat only, and may be properly called the *theoretical flame temperature* (Art. 122). Thus, for marsh gas this temperature is $\frac{5{,}780}{1.405}+60=4{,}173°$ F.; and for carbon monoxide $\frac{7{,}345}{1.405}+60=5{,}287°$ F. What is often called the flame volume of a gas explosion is the number of volumes or expansions due to the chemical heat, or for marsh gas above 0° F. $\frac{14}{1.405}=10$ volumes.

The temperature of combustion, or the temperature of the gaseous products due to the combustion, must not be confused with the temperature of ignition of gases, which will be explained later (Art. 121); the one has no necessary connection with the other.

70. Calorific Power or Heating Value.—The heating value of a few important gases and other combustibles have been given in Table 5, expressed in British thermal units per pound of combustible. This is often spoken of as the *calorific power* of a substance or a fuel, for the reason that the burning of a given weight of any fuel in a given time will develop a certain *power*, which is determined by its heating value. Thus, since one horsepower is equivalent to 2,545 B.T.U. per hour (Art. 55), the total heat of the weight of fuel burned per hour, in any case, divided by 2,545, will give the theoretical horsepower developed. For example,

$$\text{Anthracite, 100 lb. per hr.} = \frac{12{,}350 \times 100}{2{,}545} = 485 + \text{Hp.}$$

Example.—What is the theoretical horsepower developed by burning each hour a cord of dry hickory whose heating value is, say 7,000 B.T.U.?

Solution.—Taking the weight of a cord of this wood as 4,500 pounds, the theoretical power developed is

$$H = \frac{7{,}000 \times 4{,}500}{2{,}545} = 12{,}377 + \text{Hp.} \quad \textit{Ans.}$$

71. Comparison of Fuels.—Dulong, who has carefully investigated this subject, has given the following formula for calculating the heating value (B.T.U.) of a pound of coal from its ultimate analysis:

$$\text{Heating value per pound} = 146\,C + 620\left(H - \frac{O}{8}\right). \quad . \ (20)$$

The letters C, H, and O stand for the percentages of carbon, hydrogen, and oxygen, respectively. The probable error in the use of this formula does not exceed 2 per cent.

The presence of sulphur adds 40 B.T.U. for each per cent. of sulphur present, but this amount is usually so small as to be of no practical importance and is generally omitted.

The heating value or calorific power of different fuels (Table 5) is made the basis on which their comparative values are determined in practice, as illustrated by the following examples:

Example 1.—Let it be required to calculate the heating value of a coal whose ultimate analysis is C 75%, H 5%, O 15%, ash 5%.

Solution.—Substituting the given percentages in formula 20,

$$\text{Heating value} = 146 \times 75 + 620\left(5 - \tfrac{15}{8}\right) = 12{,}887 \text{ B.T.U.} \quad \textit{Ans.}$$

Example 2.—Calculate the amount of energy stored in a single pound of the coal mentioned in the last example.

Solution.—Since 1 B.T.U. is equal to 778 foot-pounds, the total energy stored in a pound of this coal is

$$12{,}887\times 778 = \text{say } 10{,}000{,}000 \text{ ft.-lb., or } 5{,}000 \text{ ft.-tons.} \quad \textit{Ans.}$$

Example 3.—How many cords of wood having a heating value of 6,000 B.T.U. will be equivalent to a ton of bituminous coal having a heating value of 11,500 B.T.U., the wood weighing 4,000 pounds per cord?

Solution.—Divide the heating value of the coal per ton by the heating value of the wood per cord; thus,

$$\frac{2{,}000\times 11{,}500}{4{,}000\times 6{,}000} = .958+ \text{cords.} \quad \textit{Ans.}$$

The cord of wood in this case is seen to have a slightly greater heating value than a ton of the coal.

Example 4.—A certain large factory is using as fuel under its boilers bituminous coal having a calorific power of 2,375 calories, at a cost of $7.65 per ton. Would it be cheaper to use coke containing 90 per cent. of fixed carbon and costing $10.50 per ton, and if so what would be the percentage of gain or saving in fuel expense?

Solution.—Since 1 calorie equals 3.9683 B.T.U. (Art. 54), the heating value of the coal is $2{,}375\times 3.9683 = 9{,}424+$ B.T.U. Again, since the coke contains but 90 per cent. of fixed carbon, its heat value per pound of coke would be .9 of the heat value of carbon (14,544 B.T.U.), or $14{,}544\times .9 = 13{,}089$ B.T.U. The B.T.U. purchased by $1 in each kind of fuel is then

$$\text{Coal,} \qquad \frac{9{,}424\times 2{,}000}{7.65} = 2{,}463{,}790 \text{ B.T.U.}$$

$$\text{Coke,} \qquad \frac{13{,}089\times 2{,}000}{10.50} = \underline{2{,}492{,}380} \text{ B.T.U.}$$

Difference in favor of coke, 28,590 B.T.U.

The percentage of saving is then

$$\frac{28{,}590}{2{,}463{,}790}\times 100 = 1.16+ \text{per cent.} \quad \textit{Ans.}$$

EXAMINATION QUESTIONS

Heat

1. Convert 5° C. into Fahrenheit degrees.

Ans. 41° F.

2. Convert −10° C. into Fahrenheit degrees.

Ans. 14° F.

3. Convert 17.6° F. into Centigrade degrees.

Ans. −8° C.

4. How many B.T.U. in 1,000 calories?

Ans. 3,968+ B.T.U.

5. How many pound-calories in 810 B.T.U.?

Ans. 450 lb.-cal.

6. How many B.T.U. are absorbed in raising the temperature of 10,000 cubic feet of dry air from 32° F. to, say 300° F., in round numbers? *Ans.* 51,360 B.T.U.

7. If the calorific power of the coal is 12,000 B.T.U., how many pounds of this coal will it be necessary to burn per hour to produce the rise in temperature mentioned in the last example, in a ventilating current of 10,000 cubic feet of air per minute passing over the mine furnace?

Ans. 220 lb. per hr.

8. A furnace shaft makes 50 gallons of water each 24 hours, and this water is evaporated, absorbing heat from the upcast air; what quantity of heat is thus absorbed per hour if the temperature of the water flowing into the shaft is 55° F., and the temperature of the air and vapor at the top of the shaft is 212° F.? *Ans.* 19,540 B.T.U. per hr.

9. If 50,000 cubic feet of air is passing into a mine at a temperature of 32° F., what will be the expanded volume of this current at a point of the return airway where the temperature has risen to 70° F., neglecting the expansion due to the decrease of pressure? *Ans.* 53,861 cu. ft.

10. If in the last example the atmospheric pressure was, say 14 pounds per square inch or 2,016 pounds per square foot, while the mine pressure in the intake airway was 14 pounds per square foot greater than upon the return airway, making the absolute pressure on the intake 2,030 and on the return 2,016 pounds per square foot, to how much would this decrease of pressure increase the volume of the return current, in addition to the increase due to temperature? *Ans.* 54,235 cu. ft.

11. If in the mine referred to in the last example the volume of the return current was found to measure 57,500 cubic feet, what volume of gas would this indicate is being given off in the mine?

Ans. 3,265 cu. ft. per min.

12. If the explosion of ordinary blasting powder produces 280 volumes of gaseous products, and the remaining solid products occupy 1/3 of the original volume of the powder, and it is assumed that the temperature of the gases at the moment of rupture, owing to the combustion of the powder not being complete, is, say 2,000° F., the original temperature before the explosion being 60° F. and the atmospheric pressure 15 pounds per square inch, what is the estimated pressure behind the tamping, and what is the ruptive pressure acting to break the coal?

Ans. Total pressure, 29,800 lb. per sq. in.

NOTE.—The ruptive pressure would be 15 pounds less than the total pressure developed in the hole, but in this case the difference is insignificant. The ruptive pressure is practically 15 tons per square inch.

13. How many foot-pounds of energy are stored in a pound of coal whose heating value is represented by 12,500 B.T.U.? *Ans.* 9,725,000 ft.-lb.

CHAPTER III

THE ATMOSPHERE.

72. The atmosphere is the gaseous envelope that surrounds the earth and fills all air spaces or cavities open to its admission.

73. **Composition of the Atmosphere.**—The gases forming the atmosphere are chiefly oxygen and nitrogen, with traces of carbon dioxide, argon, and ammonia and small varying amounts of moisture. The oxygen of the atmosphere is the great supporter of all life, and plays an important part in almost all chemical reactions; it is the chief supporter of combustion. The nitrogen of the atmosphere serves to dilute the oxygen and make it respirable; it is wholly inert, playing no part in chemical reactions excepting to dilute the other gases. It is worthy of note that for this purpose there is no other gas known that could take its place and manifest the same inertness to other elements.

The gases of the atmosphere form a mechanical mixture of almost invariable composition. These gases do not act on each other under any ordinary conditions, or combine to any appreciable extent in the atmosphere, and yet they are always found uniformly mixed in the same proportions, where the oxygen has not been absorbed by some of the various forms of combustion. Owing to this constancy of composition, the oxygen and nitrogen gases of the atmosphere have been called *air*, as though they formed a compound and were not simple gases. Roughly speaking, oxygen forms about one-fifth of the volume and one-fourth of the weight of the atmosphere or air, and nitrogen the remainder. The exact proportions in a normal state of the atmosphere, as given by Dr. Angus Smith who has investigated this subject, expressed as parts in 100 are as follows:

		By Volume	By Weight
Air	Oxygen...............	20.9	23.0
	Nitrogen..............	79.1	77.0
		100.0	100.0

74. Weight of Air.—At the present time we may say practically all calculations involving the weight of air are based upon the careful determinations of Regnault. A glass globe having a capacity of one litre was weighed first empty and then filled with dry air at a temperature of 0° C. (32° F.) and a pressure of 760 millimetres (29.92 in.). The difference made known the weight of the air at this temperature and pressure. The determination gave the following results:

1,000 c.c. = 1 litre = 1.293187 grams;
1,000 litres = 1 cubic metre = 1.293187 kilograms;
1 cubic foot = .080728 pound.

This determination made at Paris (Lat. 48° 50′) would require correction for other latitudes if a spring balance is to be used; but, in general, it will be sufficient to adopt as a standard unit, the weight of 1 cubic foot of dry air at 32° F. and a barometric pressure of 29.92 inches. When desired the corrected weight of dry air at any place (32° F., bar. 29.92 in.) may be calculated, remembering that such weight is proportional to the force of gravity. For sake of reference the value of the force of gravity is given below for a few important places and latitudes, at sea level.

TABLE 6

VALUES OF GRAVITY AT DIFFERENT LATITUDES (SEA LEVEL)

Places	Latitude	Gravity, Feet per Second	Places	Latitude	Gravity, Feet per Second
Equator......	0° 00′	32.091	Paris.........	48° 50′	32.183
Latitude 45°..	45° 00′	32.173	Greenwich....	51° 29′	32.191
Poles........	90° 00′	32.255	New York....	40° 30′	32.160

The force of gravity varies also with the height above sea level, diminishing as we ascend. The value of the force of gravity g (ft. per sec.), for any latitude L, and for any height h (ft.) above sea level may be calculated by the formula

$$g = 32.173 - .082 \cos 2L - .000003\,h \quad . \quad . \quad (21)$$

EXAMPLE.—Let it be required to calculate the force of gravity at Denver, Colorado, having a latitude of 39° 47′ N, and an elevation of 5,370 feet above sea level.

Solution.—The cosine of twice the latitude is $\cos 2(39° 47') = .18109$, and substituting these values in formula 21

$g = 32.173 - .082 \times .18109 - .000003 \times 5{,}370 = 32.142$ ft. per sec. *Ans.*

75. Formulas for Weight of Air.—Two formulas are in common use for determining the weight of a cubic foot of dry air at any given temperature and pressure. The one commonly used in mining textbooks expresses the pressure in inches of mercury, which is called the *barometric pressure;* the other, used in steam engineering practice, expresses the pressure as pounds per square inch. Owing to the use of 460 as the absolute temperature instead of the old value 459, it is necessary to use the constant 1.3273 instead of the former constant 1.3253; the results are practically the same as those obtained by the old formula. The following formula is used in mining practice:

$$w = \frac{1.3273 \times B}{460 + t}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

in which w=weight of 1 cubic foot of dry air, at a temperature t and barometric pressure B (lb.);
B=barometric pressure or height of mercury column (in.);
t=temperature of the air (deg. Fahr.).

The constant 1.3273 is the weight of a cubic foot of dry air (lb.) at an absolute temperature of 1° F. (–459° F.), and a barometric pressure equal to 1 inch of mercury (standard) (Art. 77), assuming that the laws of the expansion and contraction of gases (Art. 61) held uniform at this temperature and pressure and the air retained its gaseous form.

Example.—Calculate the weight of a cubic foot of dry air at 60° F. and 30 inches barometer.

Solution.—Substituting the given values in formula 22, the weight of the air is, in this case,

$$w = \frac{1.3273 \times 30}{460 + 60} = \frac{39.819}{520} = .076575, \text{ say } .0766 \text{ lb.} \quad \textit{Ans.}$$

The following formula will often be found useful, and gives practically the same results as formula 22 above:

$$w = \frac{p}{.37T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

in which, in addition to the symbols previously explained,

p = pressure supported by the air (lb. per sq. in.);
T = absolute temperature of the air (deg. Fahr.).

The constant .37 may be obtained by dividing the weight of 1 cubic inch of mercury at 32° F. (.4911 lb.) by the constant used in formula 22; thus

$$.4911 \div 1.3273 = .37$$

EXAMPLE.—Calculate as before the weight of a cubic foot of dry air at 60° F. and a pressure equal to 30 inches barometer.

Solution.—Since 1 cubic inch of mercury weighs .4911 pound, 30 inches of mercury column correspond to a pressure of $30 \times .4911 = 14.733$ lb. per sq. in. Also the absolute temperature is in this case $460 + 60 = 520°$ F. Therefore, substituting these values in formula 23

$$w = \frac{14.733}{.37 \times 520} = .076575, \text{ say } .0766 \text{ lb.} \quad \textit{Ans.}$$

Formulas 22 and 23 are thus seen to give identical results, but in exact calculations all barometric readings must be reduced to standard readings, as explained in Art. 77. It may be desired at times also to correct the weight obtained by either formula for latitude (Art. 74).

76. Atmospheric Pressure.—The weight of the air forming the atmosphere causes it to press with great force upon the surface of the earth. The pressure at any point is equal to the weight of air above that point. At sea level the average or mean atmospheric pressure is 14.7 pounds per square inch or 2,116.8 pounds per square foot. This pressure increases as we descend below sea level and decreases as we ascend above sea level. The pressure of the atmosphere is subject to a regular daily fluctuation, which though slight attains a maximum between the hours of 9 and 11 A.M. and P.M. and a minimum between the hours of 3 and 6 A.M. and P.M. There is also a less regular yearly fluctuation, due mostly to the change in the average temperature of the seasons and the consequent difference in the humidity of the air. The yearly fluctuation attains a maximum in the northern hemisphere in January and a minimum in July, while the reverse of this is true for the southern hemisphere. Besides these regular fluctuations atmospheric pressure is subject to very irregular and often sudden changes by reason of atmospheric storms, the approach of a storm being accompanied by a fall of pressure.

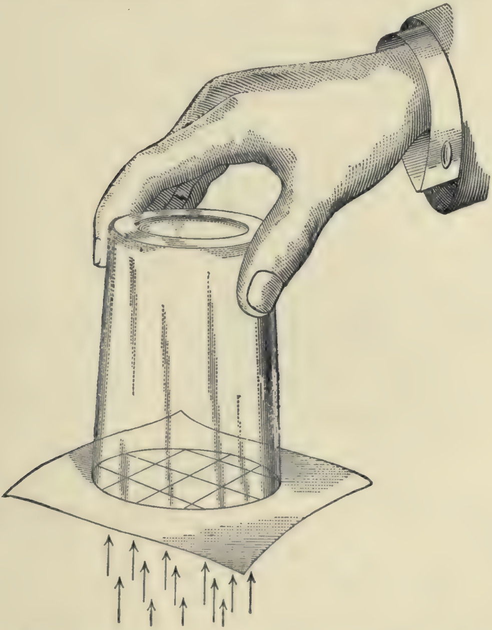

FIG. 8.—Showing Upward Pressure of the Air

Air being a fluid like water transmits pressure equally in all directions; it is not only exerted downwards as weight, but with equal force sideways and upwards. The upward pressure of the atmosphere is clearly shown by filling a tumbler to the brim with water, and placing a piece of fairly stiff paper over the tumbler, in close contact with the water, being careful to exclude all air. The paper is now held in place while the tumbler is quickly inverted and held as shown in Fig. 8. As indicated by the small arrows the upward pressure of the air on each square inch of the paper supports the weight of the water above it. The paper simply presents a solid surface to the pressure of the air.

77. The Mercurial Barometer.—The barometer is an instrument for measuring the weight of an imaginary column of air in the atmosphere. It is constructed on the principle that the weight of the air column balances and is therefore equal to the weight of the mercury column in the instrument. It consists of a glass tube about 36 inches long and closed at one end; the tube is filled with mercury, which is first boiled to expel any air it may contain. The tube is then inverted, holding the thumb tightly over its mouth to prevent the escape of the mercury while so doing, and in this position the mouth is dipped beneath the surface of mercury in a basin (Fig. 9). When the thumb is now removed the mercury column in the tube oscillates, falling and rising, and finally comes to rest with its upper surface about 30 inches above the surface of the liquid in the basin, if the experiment is performed at sea level. The height of the mercury column will be the same whatever the area of the cross-section of the tube, since the mercury column may be considered as taking the place of an imaginary air column of the same sectional area and of equal weight, or there would not be equilibrium. The small arrow-heads, in Fig. 9, represent the pressure of the atmosphere on each unit area of the surface of the mercury in the basin, except that occupied by the tube, and here the weight of the mercury column takes its place. It is evident that the weight of the mercury column calculated for an area of 1 square inch will equal the atmospheric pressure per square inch. In round numbers the atmospheric pressure at sea level, under normal conditions, supports a column of mercury 30 inches high, and taking the weight of 1 cubic inch of mercury as .49 pound this pressure is

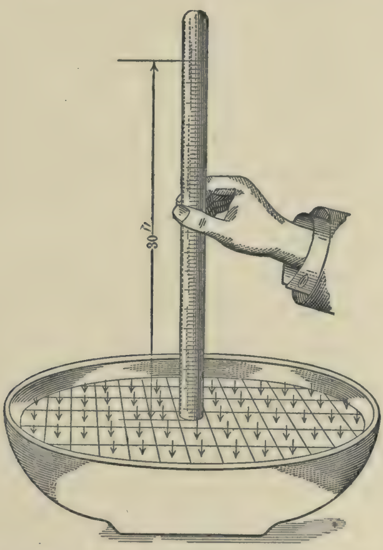

Fig. 9.—Showing Column of Mercury Balanced by the Pressure of the Atmosphere

$$.49 \times 30 = 14.7 \text{ lb. per sq. in.}$$

In Fig. 10 is shown the form of mercurial barometer in common use. The glass tube containing the mercury column is here inclosed in a metal case, with a suitable opening at its upper end for observing the height of the mercury. An adjustable vernier is here provided, that can be brought by means of the milled-head screw *a* to coincide exactly with the top of the mercury column. Because of the flow of the mercury from the cistern into the tube, and from the tube into the cistern at each rise and fall of the barometer, which changes the level of the mercury both in the cistern and in the tube, it is necessary to adjust the scale to the level of the surface of the mercury in the cistern before each reading. This is done in the barometer shown, as follows: the cistern *c* is a glass cylinder to the bottom of which is attached a bag of chamois skin holding the mercury; the surface of the mercury can be readily observed through the glass cylinder. To the barometer scale is attached a fixed ivory point projecting downwards, and held in such a position that its extreme point coincides precisely with the zero of the scale. By simply turning the screw *b*, which operates against the bag of mercury, the surface of the liquid can be quickly brought up or down, so that the ivory point just pricks its mirrored surface. The scale is then in adjustment and the vernier is now brought to the top of the mercury column by means of the screw *a* and its reading taken, which is the height of mercury supported by the atmospheric pressure.

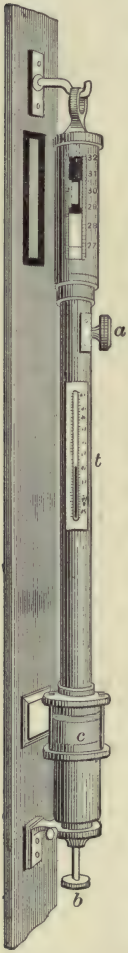

FIG. 10
The Mercurial Barometer

It is necessary that the mercurial barometer should be placed in a vertical position, and protected from the sun, wind, and weather; it should not be exposed to the high temperatures of the engine- or boiler-room, but should be placed where there is a free circulation of cool air. The thermometer *t* shown attached to the metal case of the barometer, Fig. 10, is for the purpose of observing the temperature when reading the barometer, so as to be able to correct the reading to a **standard** reading at 32° F. This is only done when special care is necessary in comparing readings taken at different temperatures. The effect of temperature on the reading of the barometer will be better understood when it is learned that, owing to the difference between the rates of expansion of the mercury and the metal case and scale, the barometer will read one-tenth of an inch higher at 69° F. than the corresponding standard reading at 32° F., for the same atmospheric pressure. Without this knowledge an observer, during a rise of temperature, might suppose the barometer was stationary when it was actually falling. The proper formula for the correction for temperature, of any particular barometer, will be furnished by the makers. It is preferable that all barometric readings should be reduced to standard readings before being recorded. Barometric readings are often spoken of as *inches of barometer*, or *inches of mercury*, or *barometric pressure*, all referring to the height of mercury column supported by the pressure of the atmosphere.

78. The Aneroid Barometer.—The aneroid is an instrument devised as a substitute for the mercurial barometer for field and for mining work, being a portable form of barometer. It consists of a metal case fitted with a graduated dial or face protected by a glass, and having a single index-hand or pointer, as shown in Fig. 11. Within this metal case is a flat, round vacuum box, whose top is corrugated in concentric rings, so as to be the more sensitive to changes of atmospheric pressure. The air has been partly exhausted from this box the top of which is supported against collapse by a strong steel spring attached to its center. The movements of this spring up and down, caused by the changes in atmospheric pressure, are communicated to the index-hand of the dial by a series of multiplying levers and a fine chain that winds about a central drum whose axis carries the pointer or hand. This instrument has been compensated for changes in temperature and graduated to correspond to the readings of the mercurial barometer. Two concentric scales mark the

Fig. 11.—The Aneroid Barometer

dial of the mining aneroid; the inner scale reads inches of mercury, while the outer scale reads feet of elevation above sea level. The divisions of the mercury scale usually indicate .02 inch, those of the altitude scale 10 feet. By means of the vernier shown in the figure, and which is operated by the milled-head screw, the altitude scale can be read to single feet. Although 31 inches is not the mean or average reading of the barometer at sea level, yet the zero of the altitude scale when fixed is made to correspond to this reading for convenience of computing elevations. Since this reading (31 in.) is in general the highest reading obtained at sea level, any corrections that may be necessary will generally be in the same direction; moreover, tables prepared for the purpose of comparing elevations with average barometric readings usually start from 31 inches at sea level.

The range of the aneroid barometer is necessarily limited, and for this reason the scale of the instrument is made to suit any desired purpose and use, at different altitudes. Mining aneroids for use at lower elevations are graduated from, say 33 to 27 inches of mercury, corresponding approximately to elevations ranging from 2,700 feet below to 2,800 feet above sea level. For mining work at higher elevations, or for surface work in coast regions, the scale is made to read from, say 30 to 24 inches of mercury, allowing an altitude range from the coast to about 6,000 feet above the sea. For mountainous regions other scales are adopted to suit the elevation, instruments being constructed to read to 20,000 feet above sea level, but at some sacrifice of accuracy.

79. Use of the Barometer.—The intelligent use of the barometer is of great importance in mining. Danger often lies in the misuse of *any* instrument, and the barometer is no exception to this rule. The relation that exists, if any, between barometric changes and the occurrence of mine explosions will be considered later (Art. 141). The primary purpose of the barometer is to determine the atmospheric pressure at any time and place. The height of the mercury column is the index of this pressure, but, owing to the change in the density of the mercury at different temperatures, this height to be a true index must be corrected for temperature; and in our treatment of the subject it will be assumed that all barometric readings are standard readings, or have been reduced to standard readings at 32° F. This being the case, the atmospheric pressure corresponding to any barometric reading is found by multiplying the reading (inches of mercury) by the weight of 1 cubic inch of mercury at 32° F., which is .4911 pound. Thus the standard barometric reading under normal atmospheric conditions at sea level is assumed as 29.92 inches, and the exact atmospheric pressure corresponding to this reading is, therefore,

$$29.925 \times .4911 = 14.696 + \text{lb. per sq. in.}$$

Either the atmospheric pressure or the barometric reading or pressure is used in calculating the weight of a cubic foot of air, as previously explained, and this unit weight of air is used to find the pressure due to any air column.

80. Atmospheric Pressure and Barometric Readings at Different Elevations.—The variation of atmospheric pressure with respect to the elevation, either above or below sea level, and its effect on the density of the air is of the greatest importance to the subject of mine ventilation. Table 7 shows at a glance the mean or average pressure and standard barometric reading (32° F.), at different elevations, together with the unit weight or weight per cubic foot of air at such elevations and for different temperatures. The table is not only useful in suggesting the effect that changes of elevation and temperature have on the efficiency of ventilating fans by altering the density of the air, but shows clearly to what extent elevation affects the efficiency of air columns and mine furnaces. It should be remembered also that the same effects are produced by *changes* of the barometer *at the same place.* The conditions with respect to the weight of air and pressure of the atmosphere are true for any corresponding barometric readings, whether at sea level or any other elevation. As given in the table, the readings represent more or less closely what is the mean or average reading for each corresponding elevation, reduced to a standard reading at 32° F.

The mercury readings given in Table 7 have been calculated for the different elevations by means of the formula

$$B_h = 29.92\left[1 \pm \frac{1}{144(.37T)}\right]^h \quad . \quad . \quad . \quad . \quad (24)$$

in which B_h = height of barometer at any elevation h (in.);

h = elevation of place above or below sea level (ft.);

T = average absolute temperature of air column from sea level to elevation h (deg. Fahr.).

In formula 24 the sign ± relates to the elevation h as being either above $(-)$ or below $(+)$ sea level. It is a difficult matter to obtain even a fair approximation to the average temperature of an atmospheric column, since the temperature does not fall regularly, especially when ascending above sea level. Numerous causes affect the temperature of the upper atmosphere, chiefly air-currents,

TABLE 7

EFFECT OF ELEVATION ON PRESSURE AND DENSITY OF AIR

Elevation, Feet	Barometer, Inches	Atmospheric Pressure, Lbs. per Sq. In.	Temperature, Deg. (Fahr.)							
			−20	0	32	60	100	200	300	400
			Weight of Dry Air, Pounds per Cubic Foot							
25,000	11.343	5.571	.0342	.0327	.0306	.0290	.0269	.0228	.0198	.0175
20,000	13.874	6.814	.0418	.0400	.0373	.0354	.0329	.0279	.0242	.0214
15,000	16.948	8.323	.0511	.0489	.0457	.0433	.0402	.0341	.0296	.0262
14,000	17.626	8.656	.0532	.0509	.0475	.0450	.0418	.0354	.0308	.0272
13,000	18.328	9.000	.0553	.0529	.0494	.0468	.0434	.0369	.0320	.0283
12,000	19.053	9.357	.0575	.0550	0514	.0486	.0452	.0383	.0333	.0294
11,000	19.805	9.726	.0597	.0571	.0534	.0505	.0469	.0398	.0346	.0306
10,000	20.582	10.107	.0621	.0594	.0555	.0525	.0488	.0414	.0359	.0318
9,000	21.392	10.505	.0645	.0617	.0577	.0546	.0507	.0430	.0374	.0330
8,000	22.229	10.916	.0670	.0641	.0600	.0567	.0527	.0447	.0388	.0343
7,000	23.088	11.339	.0696	.0666	.0623	.0589	.0547	.0464	.0403	.0356
6,000	23.975	11.774	.0723	.0692	.0647	.0612	.0568	.0482	.0419	.0370
5,000	24.890	12.224	.0751	.0718	.0671	.0635	.0590	.0500	.0435	.0384
4,500	25.360	12.455	.0765	.0732	.0684	.0647	.0601	.0510	.0443	.0391
4,000	25.837	12.689	.0779	.0745	.0697	.0659	.0612	.0520	.0451	.0399
3,500	26.322	12.927	.0794	.0759	.0710	.0672	.0624	.0529	.0460	.0406
3,000	26.813	13.169	.0809	.0774	.0723	.0684	.0635	.0539	.0468	.0414
2,500	27.315	13.415	.0824	.0788	.0737	.0697	.0647	.0549	.0477	.0422
2,000	27.824	13.665	.0839	.0803	.0751	.0710	.0659	.0559	.0486	.0429
1,500	28.339	13.918	.0855	.0818	.0764	.0723	.0672	.0570	.0495	.0437
1,000	28.861	14.174	.0871	.0833	.0778	.0737	.0684	.0580	.0504	.0445
900	28.966	14.225	.0874	.0836	.0781	.0739	.0686	.0582	.0506	.0447
800	29.072	14.277	.0877	.0839	.0784	.0742	.0689	.0585	.0508	.0449
700	29.178	14.329	.0880	.0842	.0787	.0745	.0691	.0587	.0510	.0450
600	29.296	14.387	.0884	.0845	.0790	.0748	.0694	.0589	.0512	.0452
500	29.390	14.433	.0886	.0848	.0793	.0750	.0696	.0591	.0513	.0454
400	29.496	14.486	.0890	.0851	.0796	.0753	.0699	.0593	.0515	.0455
300	29.603	14.538	.0893	.0854	.0799	.0756	.0702	.0595	.0517	.0457
200	29.710	14.591	.0896	.0857	.0801	.0758	.0704	.0597	.0519	.0458
100	29.818	14.643	.0899	.0860	.0804	.0761	.0707	.0600	.0521	.0460
Sea level } 0	**29.925**	**14.696**	**.0903**	**.0863**	**.0807**	**.0764**	**.0709**	**.0602**	**.0523**	**.0462**
− 500	30.469	14.963	.0919	.0879	.0822	.0778	.0722	.0613	.0532	.0470
−1,000	31.022	15.235	.0936	.0895	.0837	.0792	.0735	.0624	.0542	.0479
−1,500	31.582	15.510	.0953	.0911	.0852	.0806	.0749	.0635	.0552	.0487
−2,000	32.151	15.789	.0970	.0928	.0867	.0821	.0762	.0647	.0561	.0496
−2,500	32.727	16.072	.0987	.0944	.0883	.0835	.0776	.0658	.0572	.0505
−3,000	33.312	16.359	.1005	.0961	.0899	.0850	.0790	.0670	.0582	.0514
−3,500	33.903	16.650	.1023	.0978	.0915	.0865	.0804	.0682	.0592	.0523
−4,000	34.504	16.945	.1041	.0996	.0931	.0881	.0818	.0694	.0603	.0533
−4,500	35.113	17.244	.1059	.1013	.0947	.0896	.0832	.0706	.0613	.0542
−5,000	35.730	17.547	.1078	.1031	.0964	.0912	.0847	.0719	.0624	.0551

radiation from the earth, and hygrometric conditions in the air. It is sometimes assumed that the average temperature between two elevations is half way between the respective temperatures at those elevations. A closer average is obtained however by observing (Table 8) the scale of mean thermometric readings drawn from the recorded aeronautic observations of Gay-Lussac, James Glaisher, John Herschel, and others. The scale is only suggestive as to the rate of fall in temperature per thousand feet of rise above sea level. Opposite each elevation is written, in the second column, a mean observed temperature for that elevation, and in the third column, the drop or fall of temperature per thousand feet of rise. In a fourth column is given the average temperature of the air column reaching from sea level up to each elevation. These average temperatures have been calculated by finding the weight of each section of the entire air column separately, and dividing their sum by the elevation, which gives the

TABLE 8

AVERAGE TEMPERATURES OF AIR COLUMNS

For Calculating the Mean Barometric Pressure at any Elevation above Sea Level, Deduced from Observed Mean Temperatures at Different Elevations

Elevation above Sea Level, Feet	Mean Observed Temperature, Deg. (Fahr.)	Rate of Fall per 1,000 Feet, Deg. (Fahr.)	Estimated Average Temperature of Air Column, Deg. (Fahr.)
25,000	0	1.6	24
20,000	8	1.8	29
15,000	17	2.0	35
10,000	27	2.5	42
8,000	32	3.0	45
5,000	41	3.5	50
3,000	48	4.0	54
0	60	..	..

average weight of a cubic foot of the air forming that column; and from this average weight the average temperature of the fourth column was readily found for the purposes of calculation.

By substituting the above estimated, average temperatures of air columns above sea level, in formula 24, the mean barometric reading for any corresponding elevation may be calculated; for any intermediate elevation the average temperature may be found by interpolation.

Example.—Calculate the mean barometric reading for an elevation of 10,000 feet above sea level.

Solution. — The mean observed temperature (Table 8) at this elevation is 27° F., and the average temperature of air column extending from sea level up to this elevation, estimated as previously explained and as given in the fourth column of Table 8, is 42° F. The corresponding absolute temperature is $460+42=502°$ F. Substituting this value for T in formula 24

$$B_h=29.92\left[1-\frac{1}{144\times.37\times502}\right]^{10,000}=20.582 \text{ in.}\quad \textit{Ans.}$$

Note.—In the use of formula 24 a table of seven-place logarithms must be employed.

81. Effect of Gravity on Barometric Pressure.—Any increase or decrease in the force of gravity due to the latitude of the place or its elevation above sea level affects equally both the mercury and the air column, which are in equilibrium, and there is therefore no change in the barometer from this cause. Hence the height of the mercury column reduced to a standard reading (32° F.) is an absolute unit of measure for atmospheric pressure at all latitudes and elevations. All properly compensated aneroid barometers are calibrated to give standard readings (32° F.) at all temperatures, but like the spring balance the readings of the aneroid vary with the force of gravity.

When a barometric reading (inches) is converted into pounds per square foot, as in Article 79, a unit is employed that is dependent on the strength of the force of gravity, and such an expression is not therefore an absolute unit of measure. To properly define these units the word *standard*, in this connection, will be used to indicate a barometric reading reduced to an equivalent standard reading at 32° F. in accordance with Article 77, or a pressure (lb. per sq. ft.) based on the determination of the weight of air at Paris (Art. 74). It is a slight inconsistency to take the weight of a cubic foot of air at 32° F. (.080728 lb.), as determined for sea level at Paris, where the force of gravity is 32.183 feet per second, and elsewhere use the value given for gravity at New York (32.16 ft. per sec.); but as these values are so generally adopted no change will be made in them.

82. Measurement of Pressure in Atmospheres.—It is often convenient to speak of an observed pressure as being so many *atmospheres*, meaning one, two, or three, etc., times the pressure of the atmosphere at the place of observation. Air compressed to two, three, four, etc., atmospheres is regarded as being capable of the same number of expansions, this being true at all elevations. An atmosphere so regarded is a relative and not an absolute unit of measurement. The term *atmosphere* is sometimes construed to mean a pressure of 14.7 pounds per square inch, or atmospheric pressure at sea level, but this is not logical. An atmosphere can only be made a definite unit of measurement by stating the elevation or giving the barometric reading or pressure at the place of observation. It is necessary to remember that the volume of any given weight of air or gas is reduced in the same ratio as the number of atmospheres supported.

83. Moisture in the Air.—Atmospheric air is never absolutely dry. The condition of the air with respect to the amount of moisture contained, as compared with the amount the same air would contain if completely saturated, is called its *hygrometric condition*, or its degree of saturation. The capacity of air to hold moisture increases with its temperature. That is to say, the quantity of moisture required to saturate a given volume of warm air is much greater than that required to produce saturation in the same volume of air at a lower temperature, whatever the barometric pressure. For the same reason comparatively dry air in summer may often contain a much greater weight of water vapor per unit volume than very damp or moist air in winter. It is therefore important to remember that it is not the actual weight of water contained in a given volume of air that determines its humidity or hygrometric condition but rather its approach to saturation, or the limit of the capacity of the air to hold moisture. It is clear from this that air that is not saturated may be brought to a state of saturation by a fall of temperature, but the same air will not then contain any more water vapor than before. By a further fall of temperature a portion of the moisture may be deposited as water or rain, because the capacity of the air at this lower temperature is insufficient to hold the original quantity of moisture as vapor. In mines such a deposit of moisture is often witnessed on the roof and side walls or on the timbers of an airway where a warm current of air returning from the mine becomes suddenly chilled by contact with the cooler strata or colder air from the outside. In the fan drifts of large exhaust fans it is not uncommon in the winter season to find a very heavy downpour of rain produced by the condensation of the moisture when the warm return air of the mine strikes the cold sheet-iron plates that cover the drift and which are exposed to the cold outer atmosphere.

Contrary to general expectation, the weight of air per cubic foot decreases as its degree of saturation increases. In other words, moist damp air, not to say *fog*, but air approaching saturation, is lighter, volume for volume, than dry air at the same temperature and pressure. The reason for this will be better understood when it is remembered that water vapor is a gas much lighter than air, its specific gravity being .6235 (Table 4). This gaseous vapor mixes with the air as another gas, making the mixture of air and vapor lighter, bulk for bulk, than the original air. However, the mixture of gases and vapors differs materially from the mixture of gases only, as will be seen by the following laws, which are true for all such mixtures:

1. *The pressure and consequently the weight of vapor that saturates a given space at a given temperature are the same, whether that space is a vacuum or contains gas or air.*

2. *The pressure of a mixture of a vapor with gas or air is equal to the sum of the pressures that each would have if filling the same space alone.*

3. *For any given temperature there is a fixed limit to the pressure of a vapor, and therefore a corresponding limit to the weight of that vapor that will saturate a given space.*

4. *The pressure and quantity of vapor contained in a nonsaturated space or volume of gas or air is always proportional to the degree of saturation.*

Table 9 gives the pressure of aqueous vapor at the point of saturation and the corresponding mercury column, for different temperatures. The pressure of the vapor for any other degree of saturation is found by multiplying the values given in the table by the degree of saturation.

84. Weight of Moist Air.—The weight of moist air is calculated by first finding the weight of the same volume of *dry* air at the given temperature, but under a pressure equal to the given pressure less the pressure of the vapor at the given temperature. The weight of the moisture is then found separately by finding the weight of the same volume of dry air at the same temperature, but under a pressure equal to that of the vapor at such temperature, found from Table 9; the weight thus found is multiplied by the specific gravity of the vapor (.6235), and the product is the weight of the vapor contained in the air. The weight of this vapor is then added to the first weight of dry air to obtain the required total weight of moist air. The operation is expressed by the following formula, derived from formula 23:

$$w=\frac{p-c\phi}{.37T}+.6235\frac{c\phi}{.37T};$$

which readily reduces to the form

$$w=\frac{p-.3765c\phi}{.37T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

In like manner from formula 22 is derived

$$w=\frac{1.3273}{T}(B-.3765c\phi). \quad . \quad . \quad . \quad . \quad . \quad (26)$$

In the above formulas, besides the symbols already explained,

c = degree of saturation expressed as a decimal;
ϕ = pressure of vapor of saturation (lb. per sq. in.—formula 25); or (in. of mercury—formula 26).

TABLE 9

PRESSURE (TENSION) OF AQUEOUS VAPOR

Degrees, Fahr.	Barometric Pressure, Mercury (32° F.) In.	Pressure, Pounds per Square Inch	Degrees, Fahr.	Barometric Pressure, Mercury (32° F.) In.	Pressure, Pounds per Square Inch
−30	.0099	.0049	70	.7335	.3602
−20	.0168	.0082	71	.7587	.3726
−10	.0276	.0136	72	.7848	.3854
0	.0439	.0216	73	.8116	.3986
5	.0551	.0271	74	.8393	.4122
10	.0691	.0339	75	.8678	.4262
15	.0865	.0425	76	.8972	.4406
20	.1074	.0527	77	.9275	.4555
26	.1397	.0686	78	.9587	.4708
32	.1815	.0891	79	.9906	.4865
34	.1961	.0963	80	1.024	.5027
36	.2122	.1042	81	1.058	.5194
37	.2205	.1083	82	1.092	.5365
38	.2293	.1126	83	1.128	.5542
39	.2382	.1170	84	1.165	.5723
40	.2476	.1216	85	1.203	.5910
41	.2574	.1264	86	1.243	.6102
42	.2674	.1313	87	1.283	.6299
43	.2777	.1364	88	1.324	.6502
44	.2885	.1417	89	1.367	.6711
45	.2995	.1471	90	1.410	.6925
46	.3111	.1528	95	1.647	.8090
47	.3229	.1586	100	1.918	.9421
48	.3352	.1646	105	2.227	1.0938
49	.3478	.1708	110	2.578	1.2663
50	.3610	.1773	115	2.977	1.4618
51	.3745	.1839	120	3.427	1.6828
52	.3885	.1908	125	3.934	1.9318
53	.4030	.1979	130	4.504	2.2119
54	.4178	.2052	135	5.144	2.5261
55	.4333	.2128	140	5.859	2.8774
56	.4492	.2206	145	6.658	3.2696
57	.4657	.2287	150	7.547	3.7063
58	.4826	.2370	155	8.535	4.1914
59	.5001	.2456	160	9.630	4.7292
60	.5183	.2545	165	10.841	5.324
61	.5370	.2637	170	12.179	5.981
62	.5561	.2731	175	13.651	6.704
63	.5760	.2829	180	15.272	7.500
64	.5964	.2929	185	17.050	8.373
65	.6176	.3033	190	18.954	9.330
66	.6394	.3140	195	21.130	10.377
67	.6618	.3250	200	23.457	11.520
68	.6850	.3364	205	25.993	12.765
69	.7086	.3481	212	29.925	14.696

Example 1.—In Table 7 the weight of 1 cubic foot of dry air at sea level and a temperature of 60° F. is given as .0764 pound, find the weight of this air when saturated with moisture.

Solution.—The air being completely saturated, the hygrometric state is expressed as 100 per cent., or $c=1$; at a temperature of 60° F. the pressure of the vapor of saturation (Table 9) is .2545 pound per square inch; at sea level the mean atmospheric pressure (Table 7) is 14.696 pounds per square inch. Substituting these values in formula 25

$$w=\frac{14.696-.3765(.2545)}{.37(460+60)}=.07588 \text{ lb.} \quad \textit{Ans.}$$

Example 2.—Find the weight of a cubic foot of air, under normal atmospheric conditions, at an elevation of 10,000 feet above sea level, when the hygrometric condition of the air is expressed as 62 per cent., or $c=.62$, and the temperature is 32° F., using formula 26.

Solution.—Taking the values of B and ψ from Tables 7 and 9 respectively, and substituting these and the given values in formula 26, the required weight of 1 cubic foot of air under the given conditions is

$$w=\frac{1.3273}{492}(20.582-.3765\times.62\times.1815)=.05541 \text{ lb.} \quad \textit{Ans.}$$

85. Measurement of the Moisture in the Air.—The hygrometric condition of the air is determined by a small instrument called an hygrometer, of which there are numerous forms capable of a greater or less degree of accuracy. The form in most common use (Fig. 12) is that first suggested by Leslie, but often called Mason's hygrometer. It is a portable, simple instrument, consisting of two delicate thermometers attached to a single frame, and sometimes provided with a small tube fastened between them for holding water. The bulb of one of the thermometers is covered loosely with thin muslin, which is allowed to hang down so that it dips into the water, and is kept moist by the water it absorbs from the tube, or it may be wet by water poured on the muslin. The hygrometer depends on the principle that the evaporation of moisture from any wet surface is more rapid and the consequent absorption of heat greater in proportion as the air is less saturated with moisture. The evaporation from the muslin cools that bulb in proportion as the degree of saturation of the air is less, and the difference in the readings of the two thermometers is thus made the basis for the calculation of the degree of saturation of the air.

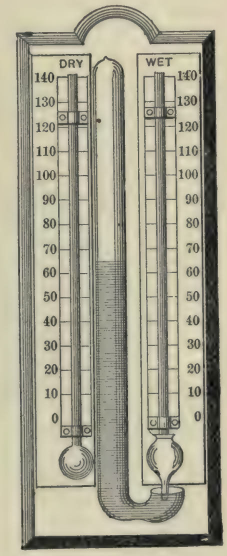

FIG. 12.—Leslie's or Mason's Hygrometer

Calling the degree of saturation of the air c, and the maximum pressure of the vapor of saturation F_1, at any temperature t_1 (Table 9), and that at any temperature t_2, F_2; the actual pressure of the vapor in the air at these temperatures is cF_1 and cF_2 (Art. 83). A formula in common use for calculating the actual pressure of the aqueous vapor in the air from the readings of the hygrometer is the following:

$$cF_1 = F_2 - \frac{B}{30}\left(\frac{t_1 - t_2}{88}\right). \quad . \ . \ . \ . \quad (27)$$

It is evident that dividing both members of this equation by the pressure of the vapor of saturation (F_1) will give the degree of saturation c, which is sought. The constant 88 relates to the specific heats of air and aqueous vapor and may be used for all temperatures above 32° F., but for temperatures below 32° F. the constant 96 should be used.

EXAMPLE.—Calculate the degree of saturation of the air when the readings of the dry- and wet-bulb thermometers are 60° and 55° F.

respectively, the barometric pressure at the time and place of observation being 28 inches.

Solution.—The pressures of the vapor of saturation (Table 9), for the given temperatures, are $F_{60} = .5183$, and $F_{55} = .4333$. Substituting these and the given values in formula 27, the actual pressure of the vapor in the air at 60° F. is

$$cF_{60} = .4333 - \frac{28}{30}\left(\frac{60-55}{88}\right) = .3803;$$

then

$$c = \frac{.3803}{.5183} = .73, \text{ or } 73\%. \quad \textit{Ans.}$$

A new and useful form of hygrometer is now manufactured* called the **hygrodeik,** in which the dry and wet thermometers are attached to an expanded fan-shaped frame. By means of an ingenious chart consisting of a series of cross lines arranged between the two thermometers the degree of saturation of the air can be read at once for any readings of the dry and wet bulbs. This obviates the necessity of any calculation and the use of the above formula.

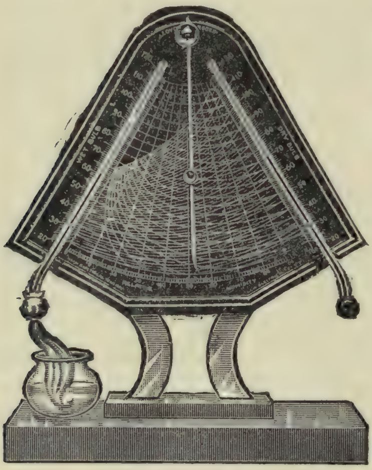

FIG. 12*a*.

The readings of the chart have been found to agree closely with the results obtained by calculation, for average barometric readings, at elevations not exceeding 3,000 feet above sea-level.

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* Taylor Brothers, Rochester, N. Y., U. S. A.

CHAPTER IV

THE COMMON MINE GASES

86. The gases commonly found in mines are but few in number; they have been enumerated in Table 1. All mine gases are known to the miner by the general term *damps*. The term has a Dutch or German origin (*Dampf*, vapor, fumes) and means suffocating or noxious gases. Later a distinction was made between the different mine gases, which had previously been regarded as *one*, and the terms *chokedamp* or *blackdamp*, *whitedamp*, *stinkdamp*, *firedamp*, and *afterdamp* came into general use to indicate the several gases now known as carbon dioxide, carbon monoxide, hydrogen sulphide, and methane; afterdamp is still called by that name, it being the variable mixture of gases resulting from a mine explosion. Among miners and many mining men, the common mine gases are better known by their old names, which, however, have fallen into disuse in chemical and other technical books. In Table 1 the several names of each gas are given, but in these pages preference will be had for the first name given, in each case, as being the proper chemical name and the one by which the gas is now most widely known.

87. Methane, Light Carbureted Hydrogen, Marsh Gas.—This is a colorless, odorless, and tasteless gas; symbol CH_4, specific gravity .559. It occurs as an occluded gas in coal seams and contiguous strata, having been produced in the metamorphism of the carbonaceous matter forming the coal, when this action has taken place with the exclusion of air and in presence of water. It is one of the earlier products of the distillation of petroleum. Being lighter than air, its tendency is to accumulate at the roof and in the higher or rise workings of the mine. The gas is combustible, burning with a pale, blue, lambent flame, such as is seen over a freshly fed anthracite fire; the pure gas will not, however, support combustion, but promptly extinguishes the flame of a safety lamp exposed to a body of the gas unmixed with air. The pure gas will not support life, but suffocates by excluding oxygen from the lungs; it is not, however, a poisonous gas, but mixed with air in sufficient quantity may be breathed for a long time with impunity, producing no other effect than a slight giddiness, which passes off on return to fresh air. This gas is detected by observing the pale blue flame cap that envelops and surmounts the flame of a safety lamp when the gas is present in sufficient quantity.

88. Firedamp.—Methane diffuses rapidly into air, forming when mixed with the air in certain proportions a very explosive mixture called by the miners *firedamp.* In England and on the continent, any mixture of marsh gas and air is called firedamp, but in this country a firedamp mixture is generally understood to be explosive or at least inflammable.

As previously stated, methane or marsh gas is combustible, but when present in small quantities in the air the dilution of the gas is so great as to prevent its ignition as a body of gas. Such small percentages of gas in the air are consumed in contact with flame or other source of heat sufficient for the purpose, and the resulting combustion of the gas gives additional heat, which in turn increases the volume of the flame. As the percentage of the gas is increased the mixture becomes inflammable at 5.55 per cent., for pure methane (Table 12), the mixture burning quietly. As the proportion of gas is further increased the combustion is more rapid and the mixture first becomes explosive at 7.14 per cent. The explosive violence now increases with the percentage of gas in the air and attains a maximum at 9.46 per cent. Beyond this point as the percentage of gas is increased the explosive violence decreases and ceases altogether when the percentage of gas in the air is about 16.67 per cent., for pure methane. The mixture of gas and air is still inflammable, however, and remains so as the percentage of gas is further increased, till there is sufficient gas present to render the mixture extinctive of its own flame, which is the case when the mixture contains 29.5 per cent. of pure methane (see also Table 17).

The explosive limits of methane have been determined for the pure gas by experiment in the laboratory, and are given below (Table 12), together with the maximum explosive point of the mixture. A firedamp mixture attains its maximum explosive force when the proportion of the air is just sufficient for the complete combustion of the gas, which is determined by calculation, as shown below. The proportions given will vary slightly from the results of actual practice, according to the character of the gas issuing from the strata, which is seldom if ever pure marsh gas.

89. Feeder Gas. — Gas as it comes from the natural strata is called *feeder gas*, and consists of a variable mixture of hydrocarbon gases, chiefly marsh gas, olefiant gas, and ethane, together with different proportions of carbon dioxide, nitrogen, oxygen, and rarely traces of carbon monoxide. Table 10 shows the amount and composition of the gaseous mixtures evolved from numerous coals at 212° F., in a vacuum. These evolved gases are an index of the possible and varied composition of feeder gas, in different localities.

Table 10

AMOUNT AND COMPOSITION OF GAS EVOLVED FROM DIFFERENT COALS AT 212° F.

Locality of Coal	Gas from 100 Grams of Coal, Cu. In.	Percentage of Evolved Gases					Remarks
		CH_4	N_2	CO_2	O_2	C_2H_6	
South Wales	3.5	.....	62.78	36.42	.80	....	Bituminous
"	3.4	63.76	29.75	5.44	1.05	....	"
"	12.2	87.30	7.33	5.04	.33	....	Steam coal
"	4.6	72.51	14.51	12.34	.64	....	Semi-bituminous
"	23.4	86.92	3.49	9.25	.34	....	Steam coal, hard
"	34.7	93.13	4.25	2.62	....	....	Anthracite
Lancashire	26.3	80.69	8.12	6.44	....	4.75	Cannel
"	21.9	77.19	5.96	9.05	....	7.80	" very hard
Westphalia	1.4	.....	89.91	7.50	2.59	....	Gas coal (20° F.)
"	1.1	24.85	58.48	2.56	4.11	....	" " "

While the most of the above analyses were made from samples of coal obtained fresh from the mine, it must be remembered that the hydrocarbon gases, marsh gas and olefiant gas, transpire and escape from the coal more quickly than carbon dioxide, nitrogen, or oxygen, the effect of which would be to reduce the percentage of the former and increase that of the latter gases, so that, in general, feeder gas coming from the strata would be richer in hydrocarbon gases and poorer in carbon dioxide and nitrogen than what is shown above. Following is a table giving the analyses of the gases coming from a few mine blowers and bore-holes.

TABLE 11

COMPOSITION OF GASES TAKEN FROM MINE BLOWERS AND BORE HOLES

Locality	CH_4	N_2	CO_2	O_2	Remarks
Dunraven mine, South Wales	96.70	2.79	.47	....	Blower
Garswood mine.............	88.86	8.90	.41	1.83	"
Karwin mine, Austria.......	99.10	.70	.20	....	"
Hruschau mine, Austria.....	79.16	17.04	.19	.61	"
Peterswald mine, Austria....	90.00	9.25	.15	.60	"
Segen Gottes mine, Germany.	87.16	11.73	1.11	....	Bore-hole
Liebe Gottes mine, Germany	77.69	18.48	3.77	.06	"

The above analyses are sufficient to show the wide variation in the composition of blower or feeder gas in different localities and different coals. It is evident that it would be unsafe to base precise expectations on any supposed composition of feeder gas, as this is too variable.

90. Inflammable and Explosive Range, Methane.—The inflammable and explosive limits of *pure* marsh gas should be known, and the effect of each of the mine gases to widen or narrow these limits should be carefully studied.

TABLE 12

INFLAMMABLE AND EXPLOSIVE LIMITS AND MAXIMUM EXPLOSIVE POINT OF METHANE (MARSH GAS), SHOWING PERCENTAGE OF GAS IN MIXTURE

Inflammable and Explosive Range	Proportion of Gas to Air		Percentage of Gas in Firedamp Mixture
	Gas (Volumes)	Air (Volumes)	
Higher inflammable limit.....	1	17.00	5.55
Higher explosive limit........	1	13.00	7.14
Maximum explosive point....	1	9.57	9.46
Lower explosive limit........	1	5.00	16.67
Lower inflammable limit.....	1	2.39	29.50

Table 12 gives both the inflammable and explosive limits and the maximum explosive point of pure methane (marsh gas), and the percentage of gas in each of these firedamp mixtures.

91. Effect of other Gases on Firedamp.—The explosive character of firedamp is greatly modified by the presence of other gases, which widen the explosive range and increase the explosive force if the gases themselves are explosive; but if not the explosive range and force of the firedamp is decreased.

(*a*) *Olefiant gas* renders firedamp more easy to ignite and increases its explosive force. In mining parlance, it makes the gas *sharp*, by which is meant the gas is fresh from the strata, and more active, agitates the flame more and obstructs the formation of the flame cap, which is always difficult to observe in sharp gas. Fresh feeder gas as it issues from the strata and before it is diluted with the mine air is generally sharp. The effect of the presence of olefiant gas is to sharpen firedamp and increase the danger from this cause.

(*b*) *Carbon monoxide* greatly widens the explosive range of firedamp, making mixtures of marsh gas and air that are inexplosive, dangerously explosive. This gas when present in firedamp invites the formation of the flame cap, and increases its height as well as the height of the flame itself. There is no trouble to obtain a good cap when carbon monoxide is present, unless its effect is counteracted by the presence of other gases. The gas intensifies the explosion of firedamp, lengthening the flame of the explosion and propagating the action.

(*c*) *Carbon dioxide* reduces the explosiveness of firedamp in proportion to the amount present in the mixture. When the firedamp is at its most explosive point, one-seventh of its volume of carbon dioxide added will render the mixture inexplosive (Table 17).

(*d*) *Nitrogen* acts to dilute firedamp and weakens its explosive force, but the gas is wholly inert and plays no other part. When firedamp is at its most explosive point, one-sixth of its volume of nitrogen added will render the mixture inexplosive.

(*e*) *Coal dust* has the same effect on firedamp as carbon monoxide, distilled from it by the flame of burning gases.

92. Carbon Monoxide, Carbonic Oxide.—This is a colorless and odorless gas; symbol, CO, specific gravity .967; it is the *whitedamp* of the miners. This gas is chiefly formed in the mine by the slow combustion of carbonaceous matter in the waste places or abandoned workings where there is little or perhaps no circulation of air; it is one of the chief products of gob and other mine fires, and is also largely produced by the explosion of powder in blasting, or the explosion of gas in mines, in a limited supply of air. It is carbon monoxide that in burning produces such large volumes of flame when black powder is used in blasting. At times the gas is not all fired, but a portion collects in the crevices and open space behind a standing shot. It is then that the miner is often burned by the unexpected flash of flame that bursts forth when he innocently puts his lamp in behind the coal to examine the effect of the blast. Carbon monoxide is also formed in large quantities whenever the flame of a blast or explosion of gas is projected into an atmosphere filled with fine coal dust. The gas is distilled from the dust by the heat of the flame. It occurs to a very slight extent only, as an occluded gas in coal. Being somewhat lighter than air, the gas has a tendency to collect at the roof and higher workings, but this tendency is so slight it is usually overcome by the movement of the air.

Carbon monoxide is combustible. It is not an extinctive gas, as is shown by the fact that lamps burn more brightly in the presence of this gas than in pure air.

Carbon monoxide is an extremely poisonous gas, being quickly absorbed by the blood when breathed into the lungs. It acts as a narcotic, producing drowsiness or stupor, followed by acute pains in the head, back, and limbs, and afterward by delirium and death if the victim is not rescued. No exact percentage of this gas can be stated as certainly producing fatal results under all conditions, as this will depend not only on the physical condition of the person and the length of time the poisonous air is breathed, but to an equal extent on the proportion of oxygen in the air. Under the conditions of mining the depletion of the oxygen of the air to a dangerous extent is not infrequent, and it is then that extremely low percentages of carbon monoxide are fatal to life. Dr. Haldane, who is probably the highest authority on this subject, states that when the oxygen has been reduced to 10 per cent., the presence of .05 per cent. of carbon monoxide will produce a fatal effect when breathed. Ordinarily it is stated that the presence of ten times this amount, or .5 per cent., of the gas may be considered as fatal to life (Art. 117).

Carbon monoxide gas is ordinarily detected in the mine by the increased brightness of the flame, which also reaches upwards in a slim taper blaze, burning quietly. Reliance should not, however, be placed on this test as making known an unsafe condition of the air in time to escape danger. The safest precaution to adopt whenever it becomes necessary to enter a place where the presence of this gas may be or is suspected is to carry along a live mouse in a small wire cage. Dr. Haldane states that so sensitive is this little animal to the effect of the gas, that it will be rendered unconscious in about one-twentieth of the time required to produce the same result in a person, thus giving ample warning in time to withdraw. Mine workings in which mice and rats thrive may be assumed to be free from any dangerous amount of white-damp, and thus these troublesome pests may prove a blessing at times. Canary birds are often used in the same manner to detect the presence of the gas.

Dr. Haldane suggests that the most delicate test for carbon monoxide, and one by which as small a quantity as .01 per cent. may be readily detected in the air, is the *blood test.* He argues that since this gas is absorbed by and affects the blood organisms, especially the hemoglobin or colored matter, it is to this the test should be applied to discover the presence of the gas. A few drops of defibrinated ox blood are first diluted 100 times with pure water, or 3 large drops of blood drawn by pricking the finger are added to a fluid ounce of water, making a buff-yellow solution. This solution is then equally divided between two test tubes (Fig. 13). One of these is provided with a long and a short glass tube passing through the cork as shown. The air to be tested is then siphoned or drawn through this test tube, entering the long tube at *a* and bubbling up through the liquid and passing out at *b*. If the air contains but .01 per cent. of carbon monoxide, the gas will impart a pink hue to the liquid, which can be best seen by comparing the liquids

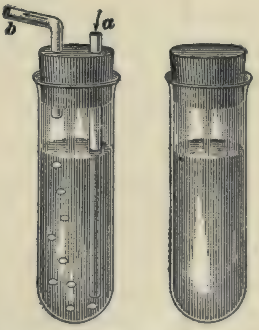

FIG. 13.—The Blood Test for Carbon Monoxide

in the two test tubes held side by side before a white sheet of paper.

When mixed with air in certain proportions carbon monoxide is explosive. The gas has the widest explosive range of any of the mine gases except hydrogen. The lower explosive limit, 1 volume of gas to 13 volumes of air, corresponds to the higher explosive limit of marsh gas. The higher explosive limit of the gas is reached when the mixture contains 1 volume of gas to 75 volumes of air (Art. 115, Table 15).

93. Poisonous Action and Effect of Carbon Monoxide. Such are the deadly effects of this gas in mining, that it is of the utmost importance to obtain the best information at hand in regard to its action and poisonous effect on the system, the symptoms of such poisoning and the most effective remedies. When air containing the smallest quantity of the gas is breathed into the lungs, the gas is rapidly absorbed by the hemoglobin or colored substance in the corpuscles of the blood to the exclusion of the necessary oxygen. Such is the affinity of these particles for the gas that they retain it with great vigor and part with what they have absorbed, with difficulty and very slowly. The poisonous effect is therefore cumulative, greatly increasing the danger of the continued breathing of air containing even the smallest percentage of the gas. Recovery from the effects of poisoning by this gas is slow. The symptoms of poisoning by carbon monoxide are palpitation of the heart and a sudden weakness in the limbs, accompanied with a sensation of giddiness just as the victim lapses into unconsciousness. It is a peculiarity of this poisoning that the victim loses his power to move before he is well aware of his danger. The victim of this gas sometimes becomes delirious and violent on being brought to fresh air. Poisoning by carbon monoxide gives to the blood after death a bright-red color, which it still retains on exposure to air.

The form of treatment first employed for cases of carbon monoxide poisoning was that suggested by Dr. J. W. Thomas, who recommended the discontinuance of alcoholic stimulants, substituting therefor the enforced inhalation of oxygen, and inducing respiration by artificial means. Later the use of peroxide of hydrogen or hydrogen dioxide (H_2O_2) has been found most efficacious. The use of stimulants is discountenanced. It is of great importance to keep the patient warm by wrapping him in blankets.

94. **Carbon Dioxide, Carbonic Acid Gas.**—This also is a colorless and odorless gas; symbol CO_2; specific gravity 1.529; it is the *blackdamp* or *chokedamp* of the miners. This gas is, for the most part, the product of the complete combustion of carbonaceous matter in a plentiful supply of air. It is largely formed in mines by the breathing of men and animals, the burning of lamps, explosion of powder, etc. It also exists in variable quantities, as an occluded gas in coal seams and the contiguous strata, and is evaporated to a limited extent from mine waters holding it in solution. Being heavier than air, its tendency is to accumulate at the floor and in the lower or dip workings of the mine. This gas is not combustible and does not support combustion; a small quantity present in the air dims the flame of the lamp, which is completely extinguished when larger quantities of the gas are present. Carbon dioxide does not support life, but suffocates by excluding oxygen from the lungs. It is not generally considered as a poisonous gas, although it produces a marked effect on the system when breathed in sufficient quantities or for a sufficient length of time. It has been suggested

these effects are not satisfactorily explained, except on the basis that the gas exerts a poisonous effect on the organisms of animal life, but as yet such poisonous effect has not been proven. The percentage of carbon dioxide necessary to extinguish a flame or to produce a fatal effect when breathed depends on the percentage of oxygen in the atmosphere in question, as will be shown later (Arts. 116 and 118).

Blackdamp is not nearly as dangerous in mines as either whitedamp or firedamp, because of the timely warning given of its presence by the dim burning of the lamps. Ordinarily an atmosphere becomes extinctive before it is irrespirable, except when poisonous gases are present; that is to say, an atmosphere in which a lamp is extinguished is usually respirable, provided no poisonous gases are present. It is, however, not only necessary, as a general rule, but prudent to withdraw promptly from an atmosphere in which lamps refuse to burn. The effect of carbon dioxide on the flame of a lamp serves as the best means for its detection. Reference has already been made (Art. 91) to the effect of this gas on firedamp. The victim of the gas should be removed to fresh air, and alternate cold and lukewarm applications made to the chest, while the limbs and body are rubbed briskly to induce circulation and efforts made to induce artificial respiration. When consciousness is restored the patient should be put to bed and kept quiet for several days and carefully watched to avoid a relapse.

95. Hydrogen Sulphide, Sulphureted Hydrogen.—This is a colorless gas, having a strong odor resembling that of rotten eggs, which gave it originally the name of *stinkdamp* among the miners. Its symbol is H_2S, and its specific gravity 1.1912. This gas is formed in the mine by the decomposition of iron pyrites or bisulphide of iron (FeS_2) in presence of moisture, the hydrogen of the water combining with the sulphur of the pyrites to form sulphureted hydrogen, while the iron is oxidized by uniting with the oxygen. It occurs, with rare exceptions, in such small quantities that it is readily carried away by the most feeble air-current and forms no accumulations in the mine; but otherwise, owing to its density, it would be found at the floor and in the lower workings of the mine. In volcanic regions it is possible to meet with larger quantities of this gas, as it is a product of volcanic action, sometimes forming a fourth of the volume of the gases emanating from such eruptions. The gas is readily soluble in water, which absorbs about three times its volume. It is combustible, burning with a blue flame like that of sulphur, and producing sulphur dioxide or sulphurous acid (SO_2) and water (H_2O). The gas unmixed with air does not support combustion or life. When mixed with 7 times its volume of air it forms a violently explosive mixture. The gas is extremely poisonous, acting to derange the system when breathed in small quantities, and producing prostration and unconsciousness when inhaled in larger quantities in the air. Its offensive smell furnishes the best means for its detection. The victim should be removed to fresh air, the body and limbs rubbed briskly and kept warm. Stimulants may be administered.

96. Olefiant Gas, Ethylene, Ethene.—This is one of the heavy hydrocarbon gases, which, associated with methane or marsh gas (CH_4) and other gases, occurs to a varying but limited extent as an occluded gas in coal seams. The symbol of olefiant gas is C_2H_4, and its specific gravity .978; it is a product of the formation of coal in the absence of water. It is a colorless gas, having a sweetish taste and a slight odor resembling ether or garlic, that often alone betrays its presence to the experienced miner. It does not occur separately in sufficient quantities to form any dangerous accumulations in the mine, but is associated with marsh gas, and exerts a marked influence on the character of the firedamp as explained (Art. 91). The gas is combustible, but does not support combustion or life. It burns with a much brighter flame than that of marsh gas and not as quietly, the flame of the safety lamp being more disturbed when this gas is present in any considerable quantity. The action of the flame in this respect, together with the faint odor of the gas, furnishes the best means for its detection in the mine.

Another of the heavy hydrocarbon gases that occurs as an occluded gas associated with methane is **ethane** (C_2H_6), specific gravity 1.0366. Like methane this gas is a product of the distillation of petroleum. Its properties are similar to those of marsh gas except it is nearly twice as heavy as that gas. It is a colorless, odorless, and tasteless gas, and when mixed with air in certain proportions is explosive. Methane and ethane are the two most important members of the *marsh gas series,* while olefiant gas or ethene is the most important of the *olefines*.

97. Nitrous Oxide.—This gas is often called laughing gas, because of the peculiar exhilarating effect it produces on the system when inhaled. Its consideration is important here since nitrous oxide often forms one of the constituent gases of the afterdamp of an explosion of gas in a mine. The symbol of nitrous oxide is N_2O, and its specific gravity 1.525; it is a colorless and odorless gas, but has a distinctly sweet taste. The gas is almost as active as oxygen in accelerating and supporting combustion; a spark or glowing ember of wood is at once kindled into flame in this gas. The burning of CO to CO_2 in this gas produces 40,400 more heat units per pound than when the same combustion takes place in oxygen. This fact reveals the possible enormous heat energy of the gas. The gas when breathed in small quantities produces unconsciousness, which is but of short duration and passes off quickly; it is not poisonous. Treat by making effort to induce artificial respiration, together with the use of a galvanic battery.

98. **Nitrogen.**—The great source of this gas is the atmosphere, where it serves to dilute the oxygen and make it fit to breathe. The gas also exists to a very large extent in some coals as an occluded gas. It has been found to form over 90 per cent. of the occluded gases in some instances. As previously stated, this gas forms practically 80 per cent. or 4/5 of the volume of the air we breathe. The various forms of combustion that take place in the mine consume the oxygen and leave large volumes of nitrogen in the return current. The diminution of the oxygen in this manner increases the poisonous effects of other gases on the system, making smaller percentages of those gases fatal to life than is the case in pure air. Nitrogen is a colorless, odorless, and tasteless gas; its symbol is N and its specific gravity .9713; the gas is not combustible and does not support combustion or life. Like carbon dioxide it dims and finally extinguishes flame when present in sufficient quantity. Though often present in large quantities, nitrogen does not tend to accumulate in the mine as a separate gas, but its tendency is to diffuse and again mix with the oxygen of the air in the proper proportion as soon as it reaches the outer atmosphere. The gas is wholly inert and has no poisonous effect; it plays no part in any chemical reaction except as a diluent.

99. Oxygen.—This is a colorless, odorless, and tasteless gas; symbol O, specific gravity 1.1056; it is the great supporter of life and combustion. Its chief source is the atmosphere, of which it forms practically one-fifth part by volume. It occurs as an occluded gas in very small quantities in some coals.

100. Hydrogen.—This is a colorless, odorless, and tasteless gas; symbol H and specific gravity .06926. Free hydrogen is of rare occurrence in mines, but is found in considerable quantities in the afterdamp of some explosions of firedamp, when the marsh gas of the firedamp mixture is in excess of that required to produce the maximum explosive force, or exceeds 9.46 per cent. (Table 12). It is not uncommon for miners to call marsh gas (light carbureted hydrogen) by the simple name of *hydrogen*, but this is of course a confusion of names that should be avoided.

THE BEHAVIOR OF MINE GASES

101. The laws that govern the motions of gases and affect their behavior in the mine are those relating to their *gravity*, *density*, *occlusion*, *transpiration* (*effusion*), and *diffusion*.

102. Gravity of Gases.—The weight of gases increases and decreases with the density of the gas and the force of gravitation, the combined effect being perhaps better described as the *gravity* of the gas. The downward or upward tendency of a gas is determined by *its* gravity with respect to the gravity of the air or other gases about it and forming its atmosphere. The heavier or lighter gas by reason of its relative gravity tends to settle lower or rise higher than the air or gases forming its atmosphere. This tendency of gases is in obedience to the law of gravitation, but its practical effect is to cause the heavier mine gases to tend to accumulate in the lower or dip workings, while the lighter gases possess a similar tendency to accumulate in the higher or rise workings of the mine.

The *temperature* of a gas is important as determining its density. A gas having a greater specific gravity than another gas may still be lighter than that gas by reason of its higher temperature. The relative temperature of the air and a body of gas often determines the position of the gas in mine workings, without apparent regard to its specific gravity.

The *accumulation* of a body of gas either in a cavity or lodging place in the roof, or in a low place or depression in the floor will depend on the gravity of the gas with respect to the position of the point where it issues from the strata. The conditions most favorable to the accumulation of gas occur when a light gas issues from the roof strata or a heavy gas issues from the floor; because in either case the gas tends to remain where it issues from the strata. On the other hand, when a heavy gas issues from the roof, or a light gas from the floor, the gravity of the gas will cause it to fall in the first case and rise in the second case, which brings the gas into contact with the air by which it is carried away. In any case, the accumulation of gas at any point in the workings of a mine will depend on whether it issues from the strata faster than the air-current takes it away.

The *stratification* of gas is frequent, both in standing gas and in air-currents containing gas. It is a matter of common experience that gas travels more or less in veins or streams, which are the result of the incomplete mixing of the gas and air. In making some laboratory tests it is often difficult to get and maintain a uniform mixture of the gas and air on this account.

The *removal of a body of firedamp* or other accumulated gases from mine workings properly belongs to the subject of Mine Ventilation.

103. Occlusion of Gases.—In the formation of coal the metamorphism of the carbonaceous matter was accompanied by the evolution of gases that varied according to the conditions coincident with the formation. It often happened that owing to the impervious character of the deposits overlying the coal these gases could not escape, but were imprisoned in the strata, being confined either in the coal itself or forced into and impregnating the strata overlying or underlying the coal. Large quantities of hydrocarbon gases, nitrogen and carbon dioxide and certain liquid bituminous matters, together with small amounts of oxygen and traces of carbon monoxide were thus entrapped in the measures. These gases are said to be occluded (hidden) in the coal and contiguous strata. It is estimated by eminent authorities on mine gases that certain coals hold, chemically, bituminous matter capable of producing from 10,000 to 12,000 cubic feet of gas per ton of coal, beside occluded gases, which are held mechanically under a compression of 200 atmospheres and which would equal 5,000 cubic feet of gas per ton of coal, if measured at the ordinary temperature and pressure. The pressure of the confined gases has in many cases been found to be equal to 500 and 600 pounds per square inch. That the actual pressure of occluded gases is much less than the estimated pressure due to their volume is perhaps owing to the absorptive power of the coal by which they are held. So great is this pressure, however, that the gas filling the pores of the coal in some instances splinters and bursts the coal from the working face of a breast, throwing it with great force in the face of the miner. The escape of the gas from the face of the coal in a gassy seam generally makes a peculiar hissing sound known to the miner as the *singing of the coal*. The escape of the gas is not usually uniform over the entire face of the coal, but occurs in spots or seams affording easier effusion. In the working of a very gassy seam the extraction of the coal sets up a movement in the overlying strata that is quite generally accompanied with audible sounds produced by the working of the gas between the foliations of the strata. The movement of the gas is always toward the opening in the seam, and this movement is the probable cause of the dull, heavy concussions of the strata, which the miners call *poundings, knockings, bumps*, etc.

104. **Transpiration or Emission of Mine Gases.**—The gases occluded in coal seams and the contiguous strata escape gradually and more or less continuously from the pores of the strata, where the latter are exposed by the operations of mining. This process is called *transpiration* or *effusion*, and continues till all the gas in proximity to the exposed faces of the coal has drained away and escaped. The transpiration of gas is always greater in new workings where fresh faces of coal are being exposed daily, provided the supply of gas is not inexhaustible. It frequently happens, however, that owing to heavy roof falls in the abandoned mine workings these workings still continue to furnish large quantities of gas after long periods of time, and often prove a serious menace to the safety of the men and the security of the mine. This is a common occurrence in mines where the gas is found in the roof or overlying strata. Owing to causes that are for the most part hidden, the transpiration of gas in a mine will sometimes cease quite suddenly, and for a long period

thereafter the mine will be free from any appreciable amount of gas, very much as an active volcano will become extinct. Again, gas will often appear in a mine previously free from gas. A change in the gaseous condition of a mine may generally be expected when approaching a fault, and the experienced miner will then use extra precaution. It is proverbial that gas follows a fault, and this is true because it is generally the line of least resistance. While a fault usually acts as a channel by which the gas escapes from that portion of the seam, it sometimes happens that gas is conducted thereby to the seam being worked, from other strata more gaseous than the seam itself. It is frequently the case that the miner loses the gas after passing through a fault, and as often perhaps fresh gas is found on the other side of the fault; so that the rule is very general that the near approach to a fault forebodes a change in the gaseous condition of the mine, and due precautions should therefore be taken.

105. Rate of Transpiration.—The laws that govern the transpiration of gases may be briefly stated as follows:

1. *For the same gas or air, the rate of transpiration varies with the pressure of the gas; in other words, the volumes of the same gas that transpire in equal times are proportional to the pressure of the gas.*

2. *For the same gas or air, the rate of transpiration decreases as the temperature of the gas increases, but not in the same proportion.*

3. *For the same gas or air, the rate of transpiration through tubes or pores of equal diameter is inversely as the length of the tube.*

4. *The rate of transpiration is independent of the material of the tube or pores through which the gas passes.*

5. *The rate of transpiration is different for different gases.*

The following table gives the relative velocities of transpiration of the important mine gases, referred to air as unity:

TABLE 13

RATES OF TRANSPIRATION OF MINE GASES, AIR = 1

Gas	Relative Velocity of Transpiration
Hydrogen	2.066
Olefiant gas	1.788
Methane	1.639
Sulphureted hydrogen	1.458
Carbon dioxide	1.237
Carbon monoxide	1.034
Nitrogen	1.030
Air	**1.000**
Oxygen	.903

Since the different gases have different rates of transpiration, the composition of the gaseous mixtures occluded in the strata is quite different from that which issues therefrom. In other words, the composition of feeder gas is always materially changed during its transpiration. As observed in the above table, the hydrocarbon gases, olefiant gas and methane, have a much higher rate of transpiration than the extinctive gases, carbon dioxide and nitrogen. Thus, 1,788 volumes of olefiant gas or 1,639 volumes of methane will transpire in the same time that is required for 1,237 volumes of carbon dioxide or 1,030 volumes of nitrogen. In a general way this fact is illustrated by comparing the occluded gases of different coals (Table 10) with the feeder gases that have transpired and filled pockets, cavities, or bore holes (Table 11). The former are rich in carbon dioxide and nitrogen, while the latter are richer in methane or marsh gas. The same cause also makes the first transpirations in a newly opened district, or the gas of virgin coal richer in hydrocarbon gases, while the emissions from older workings often contain more carbon dioxide and nitrogen and less hydrocarbon gases.

106. Gas Pockets, Feeders, Blowers.—A pocket of gas is formed whenever the gases occurring in the strata find their way into and fill a cavity or void in the rocks. This is not an infrequent occurrence. A reservoir of gas is thus formed of greater or less proportions, depending only on the size of the cavity and the supply and pressure of the confined gas. Gas pockets and gas in general are of more frequent occurrence along the axis of a broad anticline; but where the strata are much disturbed and broken the gas has generally drained away. A pocket of gas is illustrated in Fig. 14 as overlying the roof shale. The extraction of the coal in the chambers of the seam below has resulted in breaking the roof strata and crevicing the coal. The action has been greatly assisted by the enormous pressure of the gas acting on the unsupported roof. A **gas feeder** is any stream of gas issuing from a crack or crevice in the seam or in the roof or floor. A **blower** is formed when

FIG. 14.—Showing Face of Chamber and Gas Working in Roof and Coal

the gas of a feeder issues under a strong pressure. The gas contained in coal greatly assists the work of mining and cutting the coal, as it makes it more brittle and susceptible to the pick.

107. Outbursts of Gas.—An outburst of gas refers to any sudden emission of gas in large quantities from the strata; the gas may or may not be explosive. Instances are recorded of large outbursts of carbon dioxide in mines in France, where the miners were compelled to flee for their lives. Violent outbursts of marsh gas and nitrogen are of common occurrence, where the chambers and mine passages are often completely filled with hundreds of tons of broken coal and rock. The immediate cause of these occurrences is the weakening of the strata by the extraction of the coal. As illustrated in Fig. 14, the pressure of the gas frequently becomes distributed over a large area of the roof strata or the rib coal, and the roof or the coal being too weak to withstand this pressure is thrown down with great force. Gas in the roof often makes the latter heavy and should be drained by bore holes put up in the roof at intervals along the headings and chambers. Heavy outbursts of gas are generally preceded by the poundings or bumps previously described. These warning sounds are well known to the miner, who does not fail to heed them and stay out till the danger is passed. These poundings sometimes continue for several days before the outburst of gas occurs.

108. Diffusion of Gases.—When two gases, or a gas and air that do not act on each other chemically, are in contact with each other, a diffusive action at once begins between their molecules at the point of contact. Assuming that the molecules of all matter are in a state of constant motion, vibrating through a distance determined by the nature and density of the matter, it is evident there can only be a true balance and a state of equilibrium, where the matter is homogeneous in a sense that its molecules are possessed of equal kinetic energy. Any other condition prevailing at any point leaves the molecular vibrations unsupported, and the result is a procession of the molecules. The molecules of one gas are thus made to intrude among the molecules of another gas at a fixed rate of progression, causing an intimate mingling of the molecules of the two gases and the mixing of the gases in fixed proportions. This phenomenon is called *diffusion*, and is very different in its results from the accidental and ununiform mixing of gases that occurs from various causes. Diffusion produces a gaseous mixture of definite proportions, just as chemical reaction produces chemical compounds of fixed proportions.

Diffusion takes place in larger quantities in a moving current than in still air, not because the diffusion itself is more rapid, but the motion of the air constantly changes the surfaces of contact, bringing fresh air and gas together, which promotes the diffusion. For the same reason a light gas coming from the floor and having a tendency to rise, or a heavy gas coming from the roof and having a tendency to fall, will diffuse into the air more readily, owing to its position in the airway. A feeder of marsh gas in the floor is thus less liable to cause an accumulation of gas than one in the roof, because the former is largely diffused and carried away by the current, even though little air may be passing, while the latter diffuses slowly into the current, being undisturbed by gravity, and there being no force save that of the current itself to alter its surface of contact with the air. The same is likewise true with respect to carbon dioxide, which presents a far less tendency to accumulate when coming from the roof than when the feeder is in the floor.

Such are the physical conditions in mines that gases do not travel any great distance, except as they are borne on the air-current that circulates through the mine. Consequently, mine gases are found in largest proportion where they are generated or issue from the strata. The only exceptions to this rule are marsh gas in a weak air-current and carbon dioxide or blackdamp, which is often difficult to convey away, but exhibits a tendency to settle gradually to the lower parts of the mine. Blackdamp often requires a strong air-current for its removal, on this account. The results of diffusion are therefore largely confined to a comparatively small area where the gases are formed. Where marsh gas is found accumulated in distant rise workings, very little, if any, of the gas can be assumed to have traveled hither in the air-current; it has either found its way through the joints of the strata, or has issued on the spot as feeder gas, unless the air-current passing through the mine is weak. All the mine gases, with the possible exception of blackdamp (CO_2), when once absorbed by the air-current are carried by it out of the mine, and very little if any escapes to accumulate at other points.

109. Rate of Diffusion.—The laws that govern the diffusion of gases into each other and into air are quite different with respect to the rate or relative velocity of the gases from those relating to transpiration. The rate of transpiration (Table 13) has no relation to the density of the gas, except as the density is increased or decreased by the pressure under which the gases are occluded and which affects the rate of the transpiration of the gas (Art. 105). On the other hand, the rate of diffusion of each gas has been found by careful experiment to vary *inversely as the square root of the density of the gas.* Of course the pressure affects the densities of all the gases alike, and does not therefore alter their *relative* velocities or rates of diffusion. In Table 14, the several mine gases are given in the order of their relative velocities, beginning with the highest.

TABLE 14

RATES OF DIFFUSION OF MINE GASES, AIR = 1

Gas	Specific Gravity	$\frac{1}{\sqrt{\text{Sp. Gr.}}}$	Relative Velocity of Diffusion
Hydrogen	.0693	3.7987	3.8300
Methane (marsh gas)	.5590	1.3375	1.3440
Carbon monoxide	.9670	1.0169	1.0149
Nitrogen	.9713	1.0147	1.0143
Olefiant gas	.9780	1.0112	1.0191
Air	**1.0000**	**1.0000**	**1.0000**
Oxygen	1.1056	.9510	.9487
Hydrogen sulphide	1.1912	.9163	.9500
Carbon dioxide	1.5290	.8087	.8120

The values given for the relative velocities of diffusion in the last column are those determined by experiment; it will be observed these correspond closely with the calculated value of the reciprocal of the square root of the specific gravity of the gas in each case. In comparing this table with Table 13, it is interesting to note that both olefiant gas and sulphureted hydrogen, having comparatively high rates of transpiration and, as a consequence, transpiring freely when present in the coal, have lower rates of diffusion. Each of these gases when present in firedamp lower the point of ignition of the mixture. It is well they are not found in larger percentages among the occluded gases of coal seams.

The rate of diffusion of the mine gases has an important bearing on the composition and therefore the character of gaseous mixtures. While it is a fact that bodies of gas are mixed mechanically by the circulation of the air and other disturbing causes in the mine, yet this mixing is not uniform and does not produce the intimate mixture that is the result of diffusion. In any case diffusion is still at work in all gaseous mixtures to produce the uniform intimate mingling of the gases in the proportions determined by their rates of diffusion. It must not be thought for a moment, however, that ultimately all mixtures of gases in mines will be in the proportions indicated by their rates of diffusion. This is the tendency of mixtures, but owing to the many disturbing influences constantly at work these proportions are only realized under certain conditions. For example, it is observed from Table 14 that 1,344 volumes of marsh gas diffuse in the same time as 1,000 volumes of air. If diffusion acted alone in this case, the resulting mixture would contain 1,344 volumes of gas to 1,000 volumes of air, or 1 volume of gas to .744 volume of air. But since the lowest inflammable limit of marsh gas (Table 12) is 1 volume of gas to 2.39 volumes of air, this mixture does not contain sufficient air to render it either inflammable or explosive. In the mine, marsh gas transpiring from a face of coal meets with a large excess of air, and the motion of the air or that of the gas, or both, combined with other disturbing causes, often produces dangerous mixtures.

It is important that the volume of air in circulation be sufficient for the proper dilution of the gases generated, so that the mixtures formed will be neither explosive nor inflammable.

MIXTURES OF GASES AND AIR

110. It is the nature of gases to intermingle and mix freely with each other, either by diffusion in accordance with its laws, forming mixtures of definite and fixed proportions, or mechanically without uniformity and in no fixed proportion, or more frequently by both of these methods combined. In all of these there is no chemical change or reaction, but each gas retains its own identity and properties, and the properties of the gaseous mixture are the result of the combined properties of the several gases. The atmosphere is an example of a constantly uniform mixture of oxygen and nitrogen. By what means the constant proportion of these gases is maintained in the atmosphere is not known, but it is a remarkable fact that the immense consumption of oxygen, daily and hourly, makes an almost inappreciable difference between the composition of the atmosphere in a crowded city, as London or New York, and that of the open field. That the profound depth of the atmosphere forms an inexhaustible supply is the only explanation to be offered for the phenomenon. **Firedamp**, which is one of the most important of the gaseous mixtures formed in the mine, has already been explained in connection with marsh gas, it being simply a dilution of this gas with air, in explosive proportions (Art. 88). Many of the mixtures of gases, owing to their behavior or properties, are frequently mistaken by the miner for some new gas.

111. Flashdamp.—This is a common mixture of marsh gas and carbon dioxide that presents the peculiar properties of extinguishing the flame of a lamp held at the roof. After a careful investigation of the behavior of this mixture in the mine, the author has suggested for it the name of *flash-*

damp, because the flame cap afforded by the marsh gas in the mixture appears only as a momentary flash when the lamp is first raised into the mixture and then promptly disappears. The carbon dioxide present in the mixture destroys the flame cap that the marsh gas would give, but this does not occur till after the fresh air in the lamp has been exhausted. If the air lower in the airway is sufficiently fresh, the lamp when raised quickly into the gas contains, for a moment only, a fresh atmosphere that dilutes the gaseous mixture entering the lamp, and a distinct cap flashes up on the flame and as quickly disappears.

The conditions favoring the production of flashdamp are where carbon dioxide is given off from the roof of a seam generating marsh gas, or marsh gas is given off at the floor of workings full of blackdamp. In either case the conditions must be such as not to prevent the accumulation of the mixture of these gases. The formation of flashdamp is not probable where either gas becomes largely diluted with air before they diffuse into each other. The theoretical composition of flashdamp is 812 volumes of carbon dioxide and 1,344 volumes of marsh gas or methane, these being the relative velocities of diffusion (Table 14); or the ratio is 1:1.655, or, expressed as percentage, 37.66 per cent. and 62.34 per cent. of the two gases respectively. The mixture is lighter than air, having a density of .924, and it therefore has a tendency to collect at the roof. It dims the flame of a safety lamp, which is completely extinguished in pure flashdamp and sometimes even in more dilute mixtures. Flashdamp is a more dangerous mixture than firedamp: first, because it is difficult of detection and often escapes the notice of the fire boss, who mistakes it for blackdamp, and has various ways of accounting for its position at the roof; second, because of the popular fallacy that this mixture, which extinguishes the flame of a lamp, is not explosive, whereas at certain stages of dilution it becomes highly explosive.

Calculations Pertaining to Flashdamp.—

(*a*) Percentage composition:

Carbon dioxide (CO_2)	812	volumes
Methane, marsh gas (CH_4)	1,344	"
Flashdamp	2,156	"

Carbon dioxide.................... $\frac{812}{2,156} \times 100 = 37.66\%$

Methane........................ $\frac{1,344}{2,156} \times 100 = 62.34\%$

(*b*) Specific gravity:

Relative weight carbon dioxide	812(1.529) =	1,241.548
" " methane	1,344(.559) =	751.296
" " flashdamp		1,992.844

The weight of 2,156 volumes of flashdamp is therefore 1,992.844 times the weight of one volume of air at the same temperature and pressure, and its specific gravity referred to air is therefore

$$1,992.844 \div 2,156 = .924.$$

(*c*) Explosive condition:

$$\text{Flashdamp}\begin{cases}\text{carbon dioxide} \;.\; & 812 \text{ volumes}\\ \text{methane} \ldots\ldots & 1,344 \quad ``\end{cases}$$

If the flashdamp be diluted with air sufficient to bring the marsh gas to its most explosive point, the volume of the firedamp will be $1,344 \div .0946 = 14,207$ volumes; and the carbon dioxide required to render this mixture inexplosive is 1/7(14,207) = 2,029 volumes. It will be observed that the undiluted flashdamp contains only 812 volumes of carbon dioxide, and the mixture is therefore made highly explosive by the addition of air.

Conditions often occur in the mine workings where the proportion of blackdamp (carbon dioxide) in the flashdamp is so large that the mixture is heavier than air and tends to collect at the floor or other low places in the mine. This may be called *heavy flashdamp,* while the accumulation at the roof may be called *light flashdamp.* Heavy flashdamp is even more difficult to detect than light flashdamp, because of the increased dimming effect of the blackdamp, but it is not as readily ignitable or as dangerous.

112. Afterdamp.—This term describes any mixture of the gaseous products of an explosion of gas in a mine. The products of an explosion are always variable, depending on the composition of the explosive mixture and the conditions that affect the pressure and temperature of the explosion. The composition of afterdamp is therefore variable and its character changes accordingly, and may be said to be never twice alike. In a general way, afterdamp may be described as consisting of a variable mixture of gases, chiefly carbon dioxide, carbon monoxide, nitrogen, and water vapor, beside smaller amounts of nitrous oxide gas, and occasionally some unburned marsh gas or free hydrogen.

Numerous tests have shown that when marsh gas is burned in air all of the marsh gas is broken up into carbon and hydrogen if the oxygen present is not less than one-half the volume of the marsh gas (gas : air = 1 : 2.39); and with this proportion the carbon takes all of the oxygen, forming carbon monoxide only, and the hydrogen remains free, no water vapor being formed, as expressed by the equation

$$2CH_4 + O_2 + 4N_2 = 2CO + 4H_2 + 4N_2. \quad . \quad . \quad (28)$$

From this point, as the proportion of oxygen or air is increased, a small at first but ever increasing percentage of carbon dioxide is formed, and likewise a small at first but always increasing percentage of hydrogen is converted into water vapor. The increase of carbon dioxide and decrease of carbon monoxide, as the proportion of air to gas is increased, is shown by the following results (Thomas):

Gas to Air
1 : 4.5, 10% carbon forms CO_2 and 90% carbon forms CO;
1 : 5.0, 13% " " " " 87% " " "
1 : 6.0, 20% " " " " 80% " " "
1 : 9.57, all the carbon is converted into CO_2.

The point of complete combustion is reached when the proportion of gas to air is 1:9.57 (Table 12), when all of the carbon of the marsh gas is burned to carbon dioxide, and all the hydrogen is converted into water vapor, as has been expressed by equation 7 (Art. 42).

Equation 28 above expresses the reaction that takes place when the volume of the marsh gas is double that of the oxygen in the air. Since oxygen forms 20.9 per cent. of the air, the proportion of marsh gas to air would be in this case $2(20.9) = 41.8$ to 100 volumes of air; or the percentage of gas in the mixture would be

$$\frac{41.8}{100 + 41.8} \times 100 = 29.47\%.$$

Practically, then, when 29 per cent. of marsh gas is present in mine air, or, say, nearly double the amount that marks the lower explosive limit of the gas (Table 12), the burning of this mixture by reason of the explosion of a body of firedamp elsewhere in the mine would produce a volume of carbon monoxide equal to the volume of marsh gas burned, and double this volume of hydrogen and of nitrogen. This shows some of the possibilities of the gaseous composition of the afterdamp of a gas explosion.

Another important effect on the composition of the afterdamp is that produced by the incandescent carbon or burning coal dust floating in the air. The burning carbon floating in the atmosphere of the gaseous products of the explosion reduces the carbon dioxide to carbon monoxide, according to the equation

$$2CO_2+C_2=4CO. \quad . \quad . \quad . \quad . \quad . \quad (29)$$

It will be observed that the most dangerous afterdamp is formed by the explosion or burning, as the case may be, of a mixture of marsh gas and air containing more than 9.46 per cent. of gas. It must be remembered that previous to an explosion there are in different parts of the mine perhaps numerous bodies of gas, some of which are explosive, containing between 7.14 per cent. and 16.67 per cent., while others are only inflammable, containing more or less than the above percentages of gas, while still others contain so high a percentage of gas as to be not only not inflammable themselves but extinctive of the flame of the other gases, except as they may become diluted by the blast of air caused by the concussion. It must also be remembered that mixtures that are of themselves inflammable only, may be rendered explosive by reason of the carbon monoxide produced about them by the burning of dust or otherwise. It is readily seen that owing to such varying conditions and the powerful disturbances of the air throughout the mine at the moment of the explosion it would be presumption born of ignorance to attempt to fix the composition of afterdamp except in the most general way.

MINE AIR

113. It is natural to believe that when the air of a mine is fresh it does not differ materially from atmospheric air. This, however, is a mistake, since mine air at its best differs in at least two important respects from the outside atmosphere; namely, the depletion of the oxygen of the air and the contamination of the air with the mine gases. In the free outer air there are influences constantly at work to restore the purity and original freshness of the atmosphere that do not exist in the mine. One phase of this revivifying work is shown by the fact that there is actually less carbon dioxide present in the air near the surface of the earth than higher in the atmosphere, owing, probably, to the absorption of this gas by vegetation. The normal amount of carbon dioxide in the atmosphere is about 4 parts in 10,000—.04 per cent. (Thomas); or .03 per cent. (Dr. Angus Smith). Mine air, on the other hand, rarely contains less than .1 per cent., and frequent analyses have shown it is not uncommon for the miner to work all day in an atmosphere containing anywhere from 2 to 5 per cent. of this gas.

It is quite commonly supposed also that methane (marsh gas) is found in troublesome quantity only in coal mines; but the recorded explosions in the Silver Islet mine, of the Lake Superior region,* and the occurrence of the gas in varying quantities in the stratified ironstone deposits of Cleveland, the mineral veins of Colorado, the Chehsire

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* Engineering and Mining Journal, Vol. 34, page 322.

salt mines of England, the lead mines of Wales and Derbyshire, and in the salt mine at Bex, Switzerland, where jets of the gas may be seen constantly burning, leave little doubt but that methane, though commonly associated with the coal measures, may occur in dangerous quantities in any geological strata.

Sulphureted hydrogen gas occurs in largest quantity in the Sicilian sulphur mines, where the mine water is frequently saturated with the gas. Mercurial vapors contaminate the air of quicksilver mines. Besides gases, floating particles of dust, the solid matters of lamp and powder smoke, and organic matter produced by the exhalation of men and animals, and the decay of timber contaminate mine air very largely. A cheap quality of oil burned in the lamps and the practice, which is far too common among miners working at the face, of adding much petroleum (coal oil) to their sperm or lard oil do much to foul the air in many mines.

The depletion of the oxygen in mine air, by the various forms of combustion constantly going on and the breathing of men and animals, is more hurtful than what is often supposed. Dr. Angus Smith found, as the average of over 300 analyses of mine air taken in different parts of different mines, the following percentages of oxygen in seemingly good air:

Sumps	20.14 per cent
Pillar drawings	20.18 " "
Working faces	20.32 " "
Shaft bottoms (returns)	20.42 " "
Intake air-currents (inby)	20.65 " "
Large open areas	20.72 " "
Free atmospheric air	20.90 " "

Dr. Smith considers air as normally fresh when it contains 20.9 per cent of oxygen, impure when the oxygen falls to 20.6, and very bad when it reaches 20.5 per cent. However, the general ventilation of mines has very greatly improved since Dr. Smith made his observations.

114. Gaseous Condition of Mine Air.—Upon the gaseous condition of the air of a mine depends its character and classification as being a *non-gaseous*, *gaseous*, or a *fiery* mine. The gaseous condition of a mine is made known by the proportion and character of the gases that may be expected, in the natural order of events, to find their way into the air circulating at the working face. It must be accepted as a fact that mining operations will always entail a certain reasonable risk with respect to gas. However, ignorance or disregard of the prevailing conditions in any case causes heavy responsibilities to rest on the management of the mine. A fiery seam is nothing less than a fiery seam, and should be worked as a fiery seam, and anything else is to assume an unconscionable risk on the lives of men.

The old definition of a **non-gaseous** mine, as being a mine in which gas does not exist "in quantity sufficient to produce a visible cap on the flame of a common Davy lamp," cannot be accepted as a safe definition today, since Mr. William Galloway, the great exponent of the Coal Dust Theory, has stated plainly that under certain conditions common to many bituminous mines, the mine air becomes highly explosive when it contains a percentage of gas far too small to be seen on the lamp. *A mine may be classed as non-gaseous when it does not produce gas in quantity sufficient to make accident therefrom possible, under any conditions that may reasonably be expected to occur in* *the operation of the mine.* The term **non-gaseous** should convey the meaning that there is no possible risk, in this respect, in the operation of the mine, and this meaning should be duplicated in fact.

A **gassy** *or* **gaseous mine** *is a mine generating gas in any quantity that makes accident therefrom possible, under any conditions that may reasonably be expected to occur in the operation of the mine.* There are different degrees of the gaseous condition, which make numerous well-known precautions necessary in the working of the coal.

A mine may be classed as a **fiery mine** when its gaseous condition requires the constant use of safety lamps exclusively throughout the mine. This condition requires not only the rigid enforcement of strict regulations, but the greatest watchfulness, thoroughness, and caution on the part of every man employed in the mine.

The presence of gas makes itself manifest in two ways as far as endangering the health or safety of the men or the security of the mine is concerned, namely, by the effect produced on flame and by the effect on the human system. Fortunately, in almost every case occurring in the mine the former effect precedes the latter. The proposition must be studied by observing what takes place when gas is present in the mine air. All the effects destructive of life or property are produced through the medium of the atmosphere. The atmosphere of the mine furnishes the only support of the flame and transmits the force of the blast that wrecks the workings; the same atmosphere conveys to the system the poisonous gases that are fatal to life.

The several mine gases that find their way into the workings produce, according to the character and quantity of gas present:

1. An *explosive* atmosphere or condition of the air;

2. An *extinctive* atmosphere capable of extinguishing the flame of a candle or lamp, or that of burning gas;

3. A *dangerous* atmosphere affecting the respiration or even producing insensibility, or lacking little of being explosive;

4. A *fatal* atmosphere, producing fatal results when breathed but for a short time.

115. An Explosive Atmosphere.—What constitutes an explosive atmosphere cannot be defined in a few brief words. Careful experiment in the laboratory will make known the explosive limits of a gas; that is to say, the limiting proportions of gas and air between which the mixture is explosive when pure gas is used. The results of these experiments, while they are of great value in determining the relation of a gas to the phenomena of explosion, can be accepted and applied to the interpretation of what takes place in a mine only by way of suggestion. Mine gases are not pure gases, but mixtures, in varying proportions, of gases having often contrary properties. Moreover, the explosive limits of a gas vary with its pressure and temperature, and these are very uncertain elements in a mine. As a consequence, the explosive condition of mine air is subject to much and often sudden variation. An atmosphere that is safe under the ordinary conditions of heat and flame to which it is subject is often proved by sad experience to be highly explosive when exposed to the flame of a blown-out shot, or when laden with the fine dust incident to the cutting of the coal or the operations of the mine. These facts must be borne in mind when considering the safety of the mine air. Air containing a percentage of gas far too small to be detected by the lamp in the ordinary manner, and which is safe in the common meaning of that term, becomes highly explosive under the conditions that are caused by the accidental explosion of a keg of powder, or a particularly windy shot, or a blown-out shot, or a small dust explosion in a chamber. Mr. Galloway found by experiment in a mine shaft that an atmosphere containing fine coal dust was explosive when it contained but .892 per cent. of marsh gas. The following table gives the explosive range of the inflammable mine gases:

TABLE 15

EXPLOSIVE RANGE OF MINE GASES

Gas	Volume of Gas to Air	
	Lower Explosive Limit	Higher Explosive Limit
Hydrogen	1: 5	1:72
Carbon monoxide	1:13	1:75
Olefiant gas	1: 4	1:22
Methane (marsh gas)	1: 5	1:13

It is a fortunate circumstance that methane, the most abundant of all the gases occluded in coal, has the least explosive range of any of these gases; hydrogen has the widest explosive range and carbon monoxide the next. The explosive range of olefiant gas is even wider than that of methane, and its presence in firedamp adds to the danger not only by making the mixture more readily ignitable, but by making mixtures explosive that would not otherwise be explosive; that is to say, widening the explosive range. Carbon monoxide, owing to its wide explosive range and its frequent occurrence, being distilled from coal dust by the flame of an explosion, is an element of the greatest danger in mining.

There is some difference of opinion as to whether or not a simple dust-laden atmosphere is explosive in the absence of any gas whatever. Numerous experiments have been made by eminent men to prove or disprove the theory, and it is sometimes claimed that whenever an explosion of dust has occurred it has been caused by a small percentage of gas present in the air. Following an explosion of dust, in the seeming absence of firedamp, in the Campagnac Colliery (1874), M. Vital, an eminent French engineer, made some experiments on fine coal dust and air, by which he found the dust was explosive or at least inflammable in the entire absence of firedamp. Mr. Henry Hall's experiments first performed in 1876 and repeated in 1890 for the Royal Coal Dust Commission, and Mr. William Galloway's experiments (1876–80), led these men to the conclusion that the fine dust of certain inflammable coals was capable of violent explosion when ignited by a flame of sufficient volume and intensity, as, for example, the flame of a gas explosion or the flame of a blown-out shot. The presence of the smallest amount of gas both assists the ignition of the dust and increases the force of the explosion. These experiments, however, have not shown that gas is necessary before an explosion of dust can occur.

116. An Extinctive Atmosphere.—Air is extinctive when it fails to support flame; the flame is extinguished for the want of sufficient oxygen. The flame may be that of a candle, a lamp burning oil, or the flame of burning gas, but the effect is the same for the same kind of flame regardless of its size. The subject of the extinction of flame by various atmospheres has been carefully investigated by Prof. Frank Clowes, with the result that he has tabulated the extinctive atmospheres for candle, oil-fed, and gas-fed flames in three types, as follows:

1. A *residual* atmosphere, remaining when the flame dies out in the products of its own combustion in a closed space;

2. An atmosphere formed by *adding carbon dioxide* to the air till the flame was extinguished immediately upon immersion;

3. An atmosphere formed by *adding nitrogen* to the air till the flame was extinguished immediately upon immersion.

While information of this nature is suggestive and helpful in its application to mining, it represents but single instances of unadulterated atmospheres, which are never realized in mining practice. The information has a greater value in showing, as Prof. Clowes no doubt intended it should, the extinctive effect of the same atmosphere on different flames, thus showing some flames more tenacious or persistent than others. This has a relative value with respect to candles and lamp flames using wicks or gas jets, but there would be danger in assuming that the same atmosphere would be extinctive of the flames of these gases, burning freely in the atmosphere, which they dilute, instead of burning from a jet. This will be apparent from the comparison it is possible to make with respect to methane burning from a jet (Table 16), and an inflammable mixture of methane and air (Table 17), burning freely in its own atmosphere.

Table 17 has been computed by the author from data given by J. W. Thomas, with respect to the extinctive effect of gases on explosive mixtures of methane.

It is significant, in comparing the atmospheres extinctive of methane burning at a jet (Table 16) with the corresponding non-explosive atmospheres produced by adding carbon dioxide and nitrogen respectively to methane, at its most explosive point (Table 17), to observe that the

TABLE 16

RESIDUAL AND ARTIFICIAL ATMOSPHERES EXTINCTIVE OF CANDLE, OIL-FED, AND GAS-FED FLAMES.—CLOWES

Flame	Illuminant	Extinctive Atmospheres							
		Residual Atmospheres			Artificial Atmospheres				
					Carbon Dioxide Added			Nitrogen Added	
		O_2	N_2	CO_2	O_2	N_2	CO_2	O_2	N_2
Wick-fed	Candle	15.7	81.1	3.2	18.1	68.5	13.4	16.4	83.6
	Paraffin oil	16.6	80.4	3.0	17.9	67.8	14.3	16.2	83.8
	Alcohol, absolute	14.9	80.7	4.4	18.1	68.5	13.4	16.6	83.4
	" , methylated	15.6	80.2	4.2	18.3	69.3	12.4	17.2	82.8
	Colza and paraffin, equal parts	16.4	80.5	3.1	17.6	66.6	15.8	16.4	83.6
Gas-fed	Methane	15.6	82.1	2.3	18.9	71.6	9.5	17.4	82.6
	Olefiant gas	....	....	....	15.5	57.6	27.2	13.2	86.8
	Carbon monoxide	13.4	74.4	12.3	16.0	60.6	23.4	15.1	84.9
	Hydrogen	5.5	94.5	....	8.8	33.3	57.9	6.3	93.7

TABLE 17

COMPOSITION OF FIREDAMP MIXTURES RENDERED NON-EXPLOSIVE OR EXTINCTIVE OF THEIR OWN FLAME, OR INCOMBUSTIBLE BY THE ADDITION OF CERTAIN GASES

Gas Added	Effect	Composition of Mixture			
		O_2	N_2	CH_4	CO_2
Carbon dioxide	Non-explosive	16.6	62.6	8.3	12.5
Nitrogen	"	16.2	75.7	8.1	....
Methane	"	17.4	65.9	16.7	....
Methane	Incombustible	14.7	55.8	29.5	....

jet of gas was extinguished by 9.5 per cent. of carbon dioxide, the oxygen being depleted only to 18.9 per cent. On the other hand, the firedamp mixture was only rendered *non-explosive* by 12.5 per cent. of carbon dioxide, while the oxygen was depleted to 16.6 per cent. When nitrogen was added the depletion of the oxygen to 17.4 per cent. extinguished the burning jet, while a depletion of the oxygen to 16.2 per cent. only made the firedamp *non-explosive.* In either of these cases, a much wider difference would result if the firedamp mixture were to be made incombustible or extinctive of its own flame. This is clearly shown in the case of methane (Table 17), where the depletion of the oxygen by the addition of methane, in excess, to firedamp rendered the mixture non-explosive at 17.4 per cent., but it required a still further depletion of the oxygen to 14.7 per cent. to make the mixture incombustible or extinctive of its own flame. It will be readily observed that this bears directly upon the extinction of the flame of a gas explosion.

117. A Dangerous Atmosphere.—An atmosphere may be dangerous owing to its inflammability, or its near approach to an explosive condition, caused by the presence of gas or dust or both, or owing to the presence of poisonous gases. It has been explained (Art. 115) that a non-explosive mixture may be rendered explosive by reason of a surrounding atmosphere containing carbon monoxide or dust from which this gas may be generated. A dusty atmosphere always increases the explosiveness of the mine air in proportion to the fineness and inflammability of the coal. The influence of heat and pressure in increasing the explosiveness of gaseous mixtures has been fully explained (Art. 115), and need not be referred to here further than to say that it requires sometimes but a very slight concussion of the air, such as might result from the closing of a mine door, or a fall of roof, or an ordinary blast in shooting coal to precipitate trouble. These sensitive conditions depend always as much on the character of the coal as on the gaseous condition of the air, except only when considering highly explosive firedamp mixtures. Safety under these conditions lies only in vigilance and the enforcement of strict regulations designed to safeguard all the operations of the mine.

A quotation from Dr. Haldane, relating to the physiological effects of carbon monoxide when breathed in small quantities, will show that the danger of such poisonous gases in the mine air is not realized as fully as it should be by miners, who become too accustomed to the effects described to be at all apprehensive of them. Dr. Haldane is quoted as saying that .2 per cent. of carbon monoxide may prove fatal if breathed over an hour, and .1 per cent. breathed for the same time may disable a man (this amount will shortly render the movements of a mouse sluggish and his walk unsteady); .05 per cent. breathed for several hours may cause fainting or dizziness on exertion, and anything over .02 per cent. will after some time reduce a man's power to perform work.

Young men generally stand the effects of this gas better than older men, and strong men better than weak men. The depletion of the oxygen in the mine air increases the toxic effect of the gases and renders the atmosphere of the mine dangerous or even fatal when it would otherwise be safe. For example, in pure air with a normal proportion of oxygen the least percentage of carbon monoxide producing fatal results when breathed by a healthy person for about one minute is stated as .5 per cent. (Table 18); but when the oxygen is depleted to 10 per cent. in the air breathed, .05 per cent. of carbon monoxide may produce fatal results (Art. 92). This will sufficiently emphasize the danger of breathing such atmospheres.

118. A Fatal Atmosphere.—A fatal atmosphere is generally understood as being one that will produce fatal results on an average person, when inhaled for a short time only; there is, however, no distinct line of separation between a dangerous atmosphere and a fatal one. The term, as used in mining, relates to poisonous air and not to explosive conditions, although the latter may prove as fatal as the former. There are two general types of fatal atmospheres, those rendered poisonous by the presence of small quantities of a poisonous gas or gases, and those rendered irrespirable by the addition of a considerable amount of some gas that will not support life. The fatal effect in the latter case is due directly to the dilution of the atmosphere and the consequent depletion of the oxygen below the point required for maintaining the vital functions. Methane produces a very slight if any other effect, and nitrogen no other effect than that of a diluent of the air, neither of these gases being poisonous. Carbon dioxide is, for some reason not well understood (Art. 94), more harmful than the two gases just mentioned. Though not usually classed as a poisonous gas, it produces fatal results with a less depletion of the oxygen than the other gases. The following table gives the least percentages of carbon dioxide, nitrogen, and methane that when added to pure air produce atmospheres that may be considered as fatal. To this table is also appended the percentages of the poisonous gases carbon monoxide and hydrogen sulphide that are generally accepted as being the least percentages producing fatal results in a brief period of time, in otherwise good air.

Fatal results are produced more quickly on animals than on men exposed to the same atmosphere. It has been estimated that a mouse is affected in about one-

TABLE 18

COMPOSITION OF FATAL ATMOSPHERES, SHOWING LEAST PERCENTAGES OF THE PRINCIPAL MINE GASES PRODUCING FATAL RESULTS IN OTHERWISE GOOD AIR

Gas Added	Composition of Mixture			
	O_2	N_2	CH_4	CO_2
Carbon dioxide.	17.1	64.9	. . . .	18.0
Nitrogen.	7.0	93.0	. . . .	
Methane.	7.0	26.5	66.5	

Carbon monoxide. . . . . Least percentage fatal to life, .5 per cent.
Hydrogen sulphide. . . . . . “ “ “ “ “ 1.0 “

twentieth of the time required to produce the same effect on a man. For this reason a mouse carried in a small cage, when entering what may be suspected as a dangerous atmosphere, serves as a safe index of the toxic effect of the gases. There is also a considerable difference in persons in this respect. A strong, healthy person may be revived after being exposed for a long time to an atmosphere that proves fatal in a less time to a person of weak constitution or having a weak heart. Where water is at hand, a wet handkerchief placed in the mouth, or bound over the mouth and nose, is of some help in postponing the ill effects of the gas. It must be remembered that the continued burning of the lamps is not a safe index of pure air, since a lamp may burn brightly in an atmosphere that is at once fatal to life; and again, lights may be completely extinguished in an atmosphere where there is no immediate danger (Art. 94).

In a mine explosion, where the incandescent carbon resulting from the ignition of the coal dust suspended in the air acts to reduce the carbon dioxide already produced by the explosion or existing in the mine workings, large quantities of carbon monoxide are formed (Art. 112), the action being accompanied by the absorption of heat. The afterdamp produced under these conditions is extremely poisonous, and in some instances almost instantly fatal when breathed. Men have dropped in such an atmosphere almost as if shot.

CHAPTER V

MINE EXPLOSIONS

119. The term **mine explosion** describes that class of accidents that is characterized by a more or less violent disturbance of the mine air, together with the attendant destruction of life and property, as the result of the ignition and explosion of gas or fine dust contained in the mine air. Mine explosions are of three general types, embraced under the following heads:

1. Gas explosions;
2. Dust explosions;
3. Explosions of gas and dust combined.

A gas explosion possesses certain characteristics that differ materially from those of a dust explosion, and make known the nature of the occurrence and point to its possible or probable cause. The subject of mine explosions is complicated by many dependent conditions that require the most careful study and consideration to enable the mind to comprehend what may take place in the workings of a mine at the fatal moment.

120. Inflammable Mine Gases and Material.—The inflammable mine gases are methane or marsh gas, olefiant gas (ethene), ethane, carbon monoxide, and hydrogen sulphide; these have been fully described in the preceding chapter. Each of these gases forms with air a mixture that is inflammable or perhaps explosive, depending on the proportion of air present. Besides these gases it is not uncommon for the rocks of the coal measures to be impregnated, often to the point of saturation, with bitumen, petroleum, or naphtha; and these, according to the theory of an eminent English expert, Mr. James Ashworth, may vaporize so rapidly when driven out from the strata under the high pressure to which they are subject, as to satisfactorily account for such outbursts as the one that occurred at Mine No. 1, Morrissey, B. C., November 18, 1904, when the main entry was suddenly filled solid with fine coal for a distance of 450 feet from the face and 14 men were suffocated. Although it was estimated that fully 5,000,000 cubic feet of gas was given off in this outburst, every light was extinguished without ignition of the gas taking place. Mr. Ashworth ascribes this outburst to the vaporization of the petroleum or rock oil, as it is sometimes called, and naphtha impregnating the strata. However this may be, it was a remarkable instance of an outburst of gas or vapor so sudden and of such volume that the air of the mine did not serve to dilute the gas to explosive proportions, and every lamp was instantly extinguished.

121. Ignition of Gases.—The ignition of an inflammable gas takes place whenever its temperature, at any point, is raised to what is called the *temperature of ignition* for that gas, and maintained a sufficient length of time in the presence of air or oxygen. The ignition of a gas is always accompanied with the production of *flame*, which as quickly disappears whenever the temperature at a given point falls below the temperature of ignition of the gas. For this reason a flame cannot touch the surface of cool metal, but there is always a thin film or layer of cooled gas void of flame between them. It was the knowledge of this fact that led Sir Humphry Davy to surround the flame of a safety lamp with a wire gauze (Art. 148).

The ignition of a gas requires both heat and oxygen and in some cases moisture, as in the case of carbon monoxide gas, which cannot be ignited in perfectly dry air except at a very high temperature. In other cases the temperature must be maintained at the point of ignition for a certain length of time before the gas will fire. For example, the temperature of ignition of firedamp (methane and air) is 1,200° F. (Table 19), but at this temperature a time of 10 seconds is required to ignite the gas when pure or unmixed with other gases. At a temperature of 1,800° F. the time required for the ignition of pure firedamp is but 1 second, while at still higher temperatures only a fraction of a second is required.

The ignition of a gas depends on such a local concentration of heat, under conditions favorable to combustion, that the temperature of ignition is reached in the combustible itself. The intensity of the source of heat has much to do in producing this result. For example, a firedamp mixture that is only *inflammable* when ignited by a flame of low intensity, is found to be *explosive* when fired by a flame of greater intensity or by an electric spark. Ignition of a gas has also been found to occur more readily when fired from below than when fired from above. Gas in a tube, open at both ends, may burn quietly from the top of the tube, but explode if ignited from below, owing to the admixture of air and more rapid upward ignition of the gas.

Ignition supposes a rapid combustion of the body ignited, and may or may not be accompanied with flame, which is the intensely heated vapor or gas produced by the combustion. The ignition of a gas, however, may generally be considered as producing flame. The following table gives the temperatures of ignition of the common mine gases. The temperatures of ignition of both hydrogen sulphide and olefiant gas are much lower than the other mine gases.

TABLE 19

TEMPERATURES OF IGNITION OF THE INFLAMMABLE MINE GASES

Gas	Temperature of Ignition, Deg. (Fahr.)
Methane	1,200
Carbon monoxide	1,184
Hydrogen	1,148
Hydrogen sulphide	750
Olefiant gas	about 800
Ethane	" 1,000

Some interesting deductions may be drawn from the instructive experiments performed by Prof. H. B. Dixon of the University College, Manchester, and a member of the Royal Coal Dust Commission. A mixture of 1 volume of marsh gas and 13 volumes of air failed to explode in a glass tube $\frac{3}{4}$ inch in diameter and about three feet long, while a mixture of 1 part of the gas to 12 parts of air likewise failed to explode in a tube of the same length and $\frac{1}{2}$ inch in diameter, these results being due to the cooling effect of the walls of the tubes on the burning gas. The heat developed in the tube was not sufficient to cause the rapidity of combustion necessary for an explosion. In a measure this illustrates the conditions in many mine workings, especially in thin seams. While it is possible, in the larger volume of the airways of a mine, for gas to ignite when in contact with flame, yet the cooling effect of the walls of the airways may often prevent, and probably in many cases does prevent, the initiation of a destructive explosion.

Pressure assists the ignition of a gas by increasing its power to absorb heat. The absorptive power of air and gases varies greatly for different gases under the same pressure, and for the same gas under different pressures. In relation to the ignition of gas in mines, it is a significant fact that *the gases known as the inflammable mine gases all have high absorptive powers, which increase rapidly with the pressure of the gas.* For example, taking the absorptive power of air under a pressure of 1 atmosphere at sea level as unity, that of olefiant gas is 90 for a pressure equal to 1 inch of mercury, and increases to 970 for a pressure equal to 30 inches of mercury. Thus at ordinary atmospheric pressure at sea level, olefiant gas absorbs 970 times the quantity of heat absorbed by air under the same conditions. The following table gives the relative absorptive powers of some of the mine gases referred to air as unity, and is suggestive in connection with the ignition of those gases that are inflammable:

TABLE 20

ABSORPTIVE POWER OF MINE GASES

Gas	Relative Absorption of Heat, (Barom. 30 in.)
Air	1
Oxygen	1
Nitrogen	1
Hydrogen	1
Carbon dioxide	90
Nitrous oxide	355
Methane	403
Sulphurous acid gas	710
Olefiant gas	970

Pressure likewise concentrates the explosive elements, bringing the molecules of gas and air closer together, and increasing the heat energy developed per unit of volume.

122. Temperature and Volume of Flame.—The temperature of flame, like the temperature of combustion (Art. 69), is a variable factor, being even more indeterminate than the latter, owing to the large and unmeasurable addition of air. The fact is well known that the temperature of a flame is not uniform throughout, there being different stages and degrees of combustion taking place in different portions of the flame; but what is understood as the calculated or theoretical temperature of a flame is the calculated temperature of the expanded products of combustion, assuming no admixture of air other than that required for the complete combustion of the gas burned. It is true this condition may only be realized at certain points in a flame, but such a condition is most apt to be fulfilled in a mine explosion, where the supply of air is limited. The calculation of the flame temperature for methane or marsh gas mixed with air in such proportions as to produce complete combustion, the firedamp mixture being then at its most explosive point, has been explained in Article 69. This temperature is 4,173° F.; that of carbon monoxide is found in a similar manner to be 5,287° F., and that of hydrogen burning in air about 6,500° F. All of these temperatures, however, fail to be realized in practice, owing to various causes, but chiefly because the reaction that actually takes place is not correctly expressed by the chemical equation used.

The usual estimated temperature of marsh gas burning in air is about one-half of the calculated value or, say, 2,000° F.; that of carbon monoxide about 2,500° F., while the flame temperature of hydrogen is seldom estimated above 3,600° F. The uncertainty in regard to the calculated temperatures of flame is due to the fact that much is still to be learned of the manner in which the dissociation and recombination of the atoms takes place. Becquerel estimates the temperature of the alcohol flame to be 2,200° F.; Lewes places that of the tip of a tallow candle at 2,370° F.; Bunsen has found the temperature of the oxyhydrogen flame to be 5,150° F.

Attention was called in Article 69 to what is usually estimated as the volume of flame produced by the explosion of a body of firedamp at its most explosive point. The volume of this flame was found to be practically 10 times the volume of the original firedamp mixture, depending, of course, on numerous modifying conditions.

123. Heat Energy of Combustibles.—A brief glance at the heat energies developed by the burning of 1 pound each of different combustibles will be of interest and helpful by way of suggesting their relative importance in connection with mining.

TABLE 21

HEAT ENERGY OF DIFFERENT COMBUSTIBLES

Combustible	Energy per Pound, Foot-tons
Black blasting powder	360
Gunpowder	500
Guncotton	750
Nitroglycerin	1,100
Coal (anthracite), average	4,800
Coal (bituminous), average	4,600
Carbon	5.657
Methane (CH_4)	9,146
Olefiant gas (C_2H_4)	8,302
Carbon monoxide (CO)	1,682

It is observed from the above table that a very much greater energy is stored in a pound of carbon or a pound of marsh gas than in an equal weight of the most powerful explosive. Abel explains that this is probably owing to the fact that the explosive contains its supply of oxygen within itself, while carbon, coal, and other combustibles draw their supply from the air. Much of the power of the explosive is undoubtedly consumed in setting free the oxygen contained in its ingredients. It is evident, therefore, that whenever the conditions in a mine are such as to burn any considerable body of firedamp, or fine coal dust suspended in the air, an enormous explosive effect may be produced, the consequences of which it is hard to fully realize. Berthelot has drawn attention to the fact that the proper basis of comparison of the force developed by different explosives is afforded by the product of the volume and temperature of their gaseous products. Since different proportions of the heat energy are absorbed by the varying products of the combustion in each case, the heat energy of a combustible is not the measure of its explosive force, but the volume and temperature of the gaseous products, as stated above. Another authority has discriminated between what he has termed *explosive force* and *explosive effect,* considering in the latter term the element of time, or the rapidity with which the combustion that causes the explosion takes place.

The foregoing makes clear the fact that *all* combustible material is explosive to a greater or less degree, depending on the conditions that tend to accelerate or retard its rate of combustion. This is a significant fact with respect to fine coal dust held in suspension in the mine air and acted upon by a flame of considerable volume and intensity. The combustion of the dust, under these favorable conditions, may and often does take place with explosive rapidity. Ordinary black blasting powder yields on explosion 360 times its volume of gaseous products, measured at 32° F., and a barometric pressure of 29.92 inches, while the temperature of the explosion will not much exceed 3,600° F. Gunpowder yields on explosion 280 volumes of gas measured at the same temperature and pressure, while the temperature of its explosion is practically 6,000° F. Nitroglycerin yields 13,000 volumes of gas and produces an initial temperature of about 14,000° F. Coal dust may yield 2,200 volumes of gas and a temperature of 8,600° F. Marsh gas yields but one volume of gaseous products and a temperature of 5,840° F.; carbon monoxide yields but 85 per cent. of the original volume of gas and a temperature of 7,400° F. The above data all refer to explosion in a confined space, or to the initial temperature of the explosion before expansion has taken place.

124. Spontaneous Combustion. — When combustion occurs in material as a result of the natural development of heat without an apparent cause, the phenomenon is called *spontaneous combustion.* This is a common occurrence in some coal mines, particularly in seams of bituminous coal containing pyrites or sulphide of iron. The disintegration of the pyrites in presence of moisture is accompanied with the evolution of heat due to the chemical action. While this process of itself could not ordinarily develop sufficient heat to start combustion in the coal, it assists the breaking up of the coal and the exposure of fresh surfaces for the absorption of oxygen by the coal. Prof. Vivian B. Lewes of the Royal Naval College, Greenwich, attributes the spontaneous ignition of coal in bunkers to the absorption of oxygen from the air by the coal. This absorption of oxygen is common to the finest coal dust, which is thereby rendered more inflammable and dangerous (Atkinson). In the coal the absorbed oxygen is brought into direct contact with the volatile hydrocarbons of the coal, and chemical action at once takes place with the production of heat. Under favorable conditions the process thus started soon becomes self-supporting, and it is not long before the ignition of the coal takes place, followed sometimes by the ignition of the carbon monoxide produced.

It has been suggested, with much reason, that the movement of the strata incident to the extraction of the coal from a seam, accompanied as it naturally is with the evolution of heat, contributes its share toward spontaneous combustion occurring in abandoned mine workings.

125. Gob Fires.—These may be the direct result of the spontaneous ignition of fine coal and slack in the mine waste. The subject is of importance here only with respect to the gases produced and the resulting increase of danger in the workings. Carbon monoxide is produced in considerable quantity where the fire has become deep-seated and the combustion has eaten its way well under the gob, especially where the circulation of the air is slow. In a seam generating marsh gas, a gob fire is a serious menace to the safety of the mine, owing chiefly to the carbon monoxide produced increasing the explosive condition of the mine air. Moisture in the strata is favorable to the rapid extension of a gob fire.

The fine dust of many inflammable coals ignites at remarkably low temperatures; the temperature necessary for spontaneous ignition will depend on the nature of the coal, the fineness of the dust, and its exposure to the air. This temperature is variously given as 356° F. (Fayal), 284° F. (Bedson), the difference being probably owing to a difference in the above stated conditions. It is certain, however, that deposits of fine dust in the mine airways and workings may be easily ignited from causes that would hardly be suspected of producing ignition. It has been proven by experiment that, under certain conditions, an incandescent lamp gives out heat sufficient to inflame light combustible material with which it may be in contact.

A recent fire that occurred at Littleburn Colliery was caused by a workman laying a 16-candle-power electric lamp for 15 minutes on a heap of fine coal dust in an elevator hole, which he was cleaning out in readiness for the following day. The lamp had been removed and three hours later smoke was observed coming from the hole. To establish the fact that fire could result from this cause two experiments were performed. A 16-candle-power lamp was laid in a heap of fine coal dust, the dust slightly covering the lamp. Smoke came from the dust in three minutes after the current was turned on, and eight minutes later the bulb of the lamp collapsed owing to the intense heat. The lamp was then withdrawn and three hours afterward the coal was a mass of dull-red fire. When the lamp was laid loosely on top of a similar heap of dust smoke came from the coal in eight minutes, and seventeen minutes later the heat was sufficient to melt the glass and again the coal was fired as the result.* The ignition in each of these cases was greatly assisted or made possible by the oxygen absorbed by the fine dust from the air.

126. Treatment of Gob Fires.—There should be no delay, as this will greatly increase the trouble. The presence of the fire in its first stages is made known by a peculiar odor, which an experienced miner is quick to detect. The treatment in any case will depend on the stage of progress of the fire. Briefly, a small incipient fire should be located and *loaded out,* and every vestige of the heated material removed from the mine. Water, unless a suf-

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* Trans. I. M. E., Vol. XXIX, page 294.

ficient quantity be used, will generally make the matter worse after a time. Water can be used with good effect in a strong air-current; a good circulation of air is one of the best preventives of such fires, since the cooler air of the current reduces the high temperature of the workings and carries away the gases generated by the combustion. When the fire has been started by the accidental ignition of gas in the floor, and the flame has drawn back under the gob, it will be necessary to first extinguish the gas. It may be possible to do this by exploding a small stick of dynamite close to the gob, the concussion of the air often being sufficient to put out the flame. When the gas has been extinguished the trouble will cease, provided the flame has not ignited fine coal and slack, in which case it will become necessary to remove the material till the seat of the trouble is reached.

A gob fire in a room or chamber may sometimes be isolated and extinguished by closing off the room by building air-tight stoppings in all the openings thereto. When closing off a room or a number of rooms, or a section of a mine, in this manner, it is important to begin the work of building the stoppings at the return end, with reference to the circulation, and work towards the intake end of the section to be closed, in order to avoid the danger of an explosion occurring from the accumulating gases being forced out upon the lamps of the workmen. When the intake end is kept open till the last, the gases that accumulate in the affected area are driven back till the last opening is closed. When the stoppings are to be removed, the work should be commenced by slowly and carefully taking down the stopping first put up at the return end, giving the air pressure sufficient time to crowd the gases back towards this open end. A small opening may then be made in the stopping at the intake end. The work should progress slowly. The best built stoppings are never perfectly air-tight and therefore the gas always drains towards the return end of the space enclosed. Flooding a mine or any section of it in order to extinguish a gob fire that has attained considerable proportions is always the last resort, on account of the great loss of time and damage resulting to the property. At times it happens, however, that nothing else will save the mine.

127. Causes of the Ignition of Mine Gases.—The possible causes of the ignition of gas are numerous, the most common being the flame of a match or a naked lamp, a defective safety lamp, a blown-out shot, or even an ordinary safe shot if the gas has accumulated at the face, and the sparking of electric wires or motors. It is claimed gas may be ignited by the sparks from a steel pick or other tool. It is a fact, however, the old steel mill and flint was used in gassy mines as a means of light instead of lamps or candles, in order to avoid the ignition of the gas. In one or two instances it is recorded that gas was ignited by this mill, which was in use before the invention of the safety lamp. It is probable that a spark of burning steel will not ordinarily ignite a pure firedamp mixture containing no other gases. Pure firedamp has the peculiarity that a certain length of time is required for the gas to be in contact with the source of heat before ignition will take place; this time decreases as the temperature is higher (Art. 121). The presence of any gas, as hydrogen sulphide (H_2S) or olefiant gas (C_2H_4) having a lower temperature of ignition, or the presence of fine dust suspended in the air, which dust may be ignited at a temperature of, say from 300° to 350° F. (Art. 125), will greatly hasten the ignition of the gas.

With regard to sparks causing the ignition of gas much depends on the character of the burning spark as well as that of the gas. For example, it is impossible to ignite a pure firedamp mixture containing no other gas than marsh gas with the glowing embers of a wood fire, provided these are not fanned into a flame. The glowing remains of an extinguished match held over a gas jet fails to ignite the gas. A spark caused by a steel pick striking a sulphur ball (iron pyrites) and due to the burning of a fine particle of the steel, or perhaps the burning of hydrogen sulphide, seldom fails to ignite firedamp. The term *pyrites* means *fire producer*. The sparks from the copper brushes on the commutator of an electric motor will not ordinarily ignite firedamp, unless dust or some easily ignitable gas is present to assist the ignition, but when carbon brushes are employed, although sparking may occur less frequently, the ignition of the gas is almost certain to take place, even when the firedamp is quite pure. This is due to the greater intensity of the combustion of the carbon spark.

The breaking of an incandescent lamp may or may not be accompanied with the ignition of surrounding gas, depending on the character of the lamp, the manner in which it is broken, and to some extent on the character of the firedamp mixture and the temperature of the mine air. These lamps are of two general types: a lamp constructed for a low voltage and strong current has a short thick filament, while a lamp designed for a high voltage and weak current has a long thin filament. If the filament is not broken, but remains intact when the glass is shattered, it becomes almost dark for a moment immediately after the glass is broken. This is due to the cooling effect of the expanding air and gas that rush into the vacuous space of the broken globe. In another moment the filament again glows and burns out with a spark that is quite certain to ignite the gas. It is more common, however, in mining practice, for the filament to be broken by the same blow that shatters the glass. In this case the breaking of the filament occurs during the brief moment of cooling when the filament is dark, and there is therefore no sparking and no ignition of the gas takes place. It is evident from this explanation, which conforms strictly to the results of careful experiments, that the long slender filament of the high-voltage lamp is the safer of the two for two reasons: it is more sensitive to the cooling effect and also less liable to remain unbroken when the glass is shattered and to cause sparking by burning out in the air.

Gas issuing from a feeder under a great pressure and with high velocity is not as susceptible to ignition at the point of issue as farther away, where the gas has expanded, owing to the cooling effect due to the expansion and the lack of sufficient oxygen to render the gas inflammable before diffusion has taken place.

128. The Initiation of a Mine Explosion.—The ignition of a body of gas in mine workings does not necessarily lead to a mine explosion. Much, of course, depends on the explosive character of the firedamp, and the temperature and the condition of the mine air and workings with respect to gas, dust, and moisture, and the intensity and volume of the flame causing the ignition. These all may contribute to cause an explosion that would not otherwise be possible. Aside from these contributory causes, however, the initiation of a mine explosion requires a conservation of heat energy that is only possible, in the less explosive mixtures, when the physical surroundings such as relate to the size or the immediate air-space of the workings are favorable.

Another experiment performed by Prof. Dixon throws much light on this part of the subject, and enables us to surmise at least, in regard to what may and probably often does occur when a body of gas is ignited in mine workings. The experiment is a simple one: a glass tube about 4 feet in length and $\frac{3}{4}$ inch in diameter was filled with a fire-damp mixture. The combustion, slow at first, vibrated backward and forward in the mouth of the tube with ever increasing intensity and amplitude, causing a fluttering of the flame and agitating the air and gas in the tube. This continued for a moment only, when suddenly the flame darted the entire length of the tube, and the explosion was complete. In a mine the conditions affecting the initiation of an explosion are manifold, and it is probable there is every degree of variation in this respect, from an instantaneous and blinding flash accompanying the ignition of the gas, to a quiet flame sweeping majestically forward and back, and finally developing its full explosive strength within a radius of, say 20 yards from the initial point where the ignition took place. In the latter case the action is cumulative instead of instantaneous. Whether or not an ignited body of gas in mine workings will amass sufficient strength to manifest explosive violence is wholly dependent on conditions such as those previously mentioned, relating to the character and temperature of the gas-charged air and the immediate air-volume of the workings.

129. A Gas Explosion.—The conditions that affect any explosion in a mine are so numerous and varied that it is difficult to point out the special characteristics that would *in every case* distinguish an explosion of a particular class.

It may be stated, however, that in general a typical gas explosion developes *centers* of greatest violence in those localities where gas issues from the strata or tends to accumulate. While it is true that, in any explosion of gas or dust, violence is manifested wherever resistance is offered to the free expansion of the air and gases produced, yet in a true gas explosion the centers of violence are more pronounced than in a dust explosion, and the lines of force radiate in all directions from these centers, often producing seemingly contradictory evidence of the direction taken by the main blast. A gas explosion will develop its force anywhere within a radius of 20 yards from any center, and the force so developed may be transmitted with lightning rapidity to distant parts of the mine, leaving scarcely a trace of evidence that the blast has traveled over the intervening roadways or passages.

It is very rare that a mine explosion of any magnitude is a simple gas explosion. It may originate as a gas explosion, caused by the ignition of a body of firedamp; and at different points throughout the workings it may develop the characteristics of a gas explosion, where the flame ignites isolated bodies of gas; but in a large majority of cases, coal dust or blasting powder it may be has played an important part in the propagation of the flame and the maintenance of the high temperature of the expanding gases that is necessary to keep alive the flame.

130. A Dust Explosion.—The essential feature of a dust explosion is the manner in which it subsists. A dust explosion feeds upon material scattered in its path; it cannot, therefore, choose its own path, but must follow those passages that promise the largest sustenance, or afford the most abundant supplies of dust and oxygen. Both of these are necessary to the maintenance of the explosion. One of the characteristics of a dust explosion is the large volume of combustible gas produced, and likewise the large volume of oxygen required for the maintenance of the combustion. As explained in Articles 69 and 122, the flame temperature of carbon monoxide, which is the chief product of a dust explosion, is much higher than that of methane or marsh gas, and the expansion due to this cause is relatively greater. Notwithstanding this, however, the high temperature of the expanding gases is more easily maintained in a dust explosion than in a gas explosion, owing to the distribution of the combustible material and its abundance. With the high temperature of the gases generated in a dust explosion all that is required to produce flame in the mine workings and passages traversed by the blast is oxygen, which can only be obtained in a continuous supply in the direction of the intake air-current. It is owing to this fact that one of the distinguishing characteristics of a dust explosion is the persistence with which it seeks the intake air and feeding upon this air advances against the current. The flame of such an explosion never extends very far in the direction of the return air, because in this direction it is quickly snuffed out in its own trail or the products of its own combustion. The distance a dust explosion will advance along the return airway of a mine will depend on the volume of the workings, the size and condition of the airways, and the amount of available oxygen in the mine air in this direction.

The action of a dust explosion is not as sudden as that of a gas explosion, for the reason that two operations are necessary for its completion: first, the conversion of the fine dust suspended in the air into carbon monoxide; and second, the burning of this gas to carbon dioxide. Both of these operations require oxygen. The following are the important factors that determine the character of a dust explosion:

1. The physical character of the dust; its fineness, inflammability, and porosity.
2. The free suspension of the dust in the air.
3. The temperature and hygrometric condition of the air.
4. The volume and intensity of the flame causing ignition.
5. The size of the openings or volume of the workings.
6. The condition of the mine with respect to dust and moisture.

While a dust explosion is less sudden in its action, it may be fully as destructive or even more so than a gas explosion. It is always more persistent, that is to say, it has a greater power of continuance, owing to the high temperature of the combustion and the wide explosive range of the carbon monoxide, which is the chief component of its gaseous products.

131. History of Coal Dust as a Theory.—Formerly all large mine explosions were attributed to gas. The earliest recorded mention of coal dust in connection with a mine explosion occurs in an account of the Wallsend Colliery explosion, September 3, 1803, given by Mr. Buddle, a North Country viewer, England. In this explosion 13 men and boys were killed. The narrator in describing the explosion states: "The survivors more distant from the point of the explosion were burned by the shower of red-hot sparks of the ignited dust driven along by the force of the blast." In an article written by Robert Bald, a distinguished mining engineer of Scotland, and published in 1828, the possible ignition of coal dust by a blast of flame was ably discussed.

That the dangerous nature of coal dust in connection with mine explosions was known and recognized at this time is plainly shown by the report of Professors Faraday and Lyell, made in 1845 to the Home Office, regarding the fatal explosion at the Haswell Collieries, September, 1844. In relation to coal dust the report reads as follows: "In considering the extent of the fire from the moment of the explosion, it is not to be supposed that firedamp was its only fuel; the coal dust swept by the rush of wind and flame from the floor, roof, and walls of the works would instantly take fire and burn if there were oxygen enough present in the air to support its combustion. We found the dust adhering to the faces of the pillars, props, and walls, in the direction of and on the side towards the explosion, increasing gradually to a certain distance as we neared the place of ignition. This deposit was in some parts half an inch, in others almost an inch thick; it adhered together in a friable coked state. When examined with the glass it presented the fused round form of burnt coal dust, and when examined chemically and compared with the coal itself reduced to powder it was found to be deprived of the greater portion of the bitumen, and in some instances entirely destitute of the same. There is every reason to believe that much coal gas was made from this dust in the very air itself, of the mine, by the flame of the firedamp, which raised and swept it along, and that much of the carbon of this dust remained unburnt only from want of air."

Later, in discussing this explosion at the Royal Institution, Prof. Faraday said: "The ignition and explosion of the [firedamp] mixture would first raise and then kindle the coal dust that is always pervading the passages, and these effects must, in a moment, have made the part of the mine that was the scene of the calamity glow like a furnace."

Following this, experiments were made in England and in France for the purpose of ascertaining if possible the precise nature of fine dust with respect to explosions, and when the fatal Seaham explosion took place at Durham, England, September 8, 1880, in which 164 lives were sacrificed, there were found many strong advocates of the dust theory. Among these were Sir Frederick Abel, Henry Hall, William Galloway, J. B. and W. N. Atkinson, James Ashworth, and others. From this time dust took the place of gas in the explanation of mine explosions. There were yet, however, vital points of difference that remained at that time and are still largely unsettled.

The experiments of Mr. Henry Hall, inspector of mines, West Lancashire district, in 1876, and repeated for the Royal Coal Dust Commission in 1890, were conducted on a large scale in abandoned drifts and in shafts placed at his disposal by their owners for the purpose. These experiments will ever be memorable, owing to their importance and to the care with which they were executed. The first series of six experiments was performed in an old shaft 150 feet deep and 7 feet in diameter, April 30 to May 21. A cannon 2.5 feet long with a 2-inch bore was placed pointing upwards, at the bottom of the shaft. A quantity of fine coal dust was thrown into the shaft from the top, so as to saturate the air with the fine floating particles of dust. Four explosions resulted from the six trials, all but one of these causing a burst of flame into the air above the mouth of the shaft. In one instance, when the dust failed to ignite on the first discharge of the cannon, a second shot was fired two hours later, with the result that the dust then remaining in the air exploded with considerable violence. No dust had been added between these two shots, but the ignition of the dust may have been assisted by some carbon monoxide remaining in the shaft after firing the first blast.

A second series of six experiments was made on June 26 in a shaft 390 feet deep and 18 feet in diameter. The shaft was very wet, and the cannon was placed on a scaffold at a depth of 300 feet from the surface, where a cross-heading connected with another shaft. The experimental shaft was in process of sinking. A coke fire was placed on the scaffold to render this shaft an upcast. Owing probably to the large volume of the shaft and the ample space below and at the side for the expansion of the gases produced by the blast there was no ignition of the dust and no explosion resulted in any of these trials. Mr. Hall attributes the failure to ignite the dust in these experiments both to the wet condition of the shaft and its large volume, which permitted the rapid expansion of the gases and the dissipation of the heat energy of the blast. It is quite probable, however, the carbon dioxide resulting from the coke fire in this shaft played an important part by reducing the explosiveness of the air in the shaft.

The third series of eighteen experiments occupied eight days, and was performed in a shaft 630 feet deep and 8 feet in diameter. As before, there were two shafts, in this case only 63 feet apart. The cannon was placed on a scaffold at a depth of 540 feet below the surface, where a small brick-lined manway 10 square feet in area connected the two shafts. At the foot of these shafts was a somewhat larger connection, in which considerable water had accumulated. There was a current of air traveling down the one shaft and up the experimental shaft at a velocity of 100 feet a minute, which was nearly or quite saturated with moisture. The five trials, July 30, resulted in three explosions, giving flame in two of these extending 30 and 40 feet into the air. The six trials, October 17, gave three explosions with flame above the shaft in one case only. The seven trials, October 20, gave two explosions without flame; but the seventh and last proved the most violent explosion of all, the flame rising 60 feet in the air, accompanied with a continuous roar and rush of flame that lasted 5 or 6 seconds. Mr. Hall states that he was perfectly satisfied in these experiments that there was no firedamp present in the shafts. The analysis of the air passing through the shafts, taken during the progress of the experiments, showed oxygen 20.50%; nitrogen 79.20%; carbon dioxide .15%; and sulphur dioxide .09%.

The questions still in dispute, however, are as to whether or not a dust explosion is possible in the entire absence of gas (CH_4); whether or not a cloud of dust can be ignited by the ordinary flame of a lamp; and whether or not any system of sprinkling practicable in mining will avail to arrest an explosion of dust in a mine when such an explosion has once gained headway. To ascertain the true relation of fine dust of any kind to mine explosions, and if possible to clearly define the danger due to its presence and suggest practicable means of dealing with the evil, important commissions have been appointed from time to time, and elaborate experiments have been made by the governments of England, France, Austria, and Belgium. The results of these investigations are briefly summarized below.

The French Firedamp Commission, led by the eminent mining experts MM. Mallard and Le Chatelier in 1882 rejected the idea that coal dust could play any important part in a large mine explosion. Two years later, however, the Prussian Firedamp Commission in 1884, having completed an extensive series of experiments at Saarbrücken, concluded that certain fine, inflammable dusts when ignited by a blown-out shot carry the flame to considerable distances beyond the limits of the dust deposits, and produce explosive results in the complete absence of any trace of firedamp, the resulting phenomena being similar to those produced by other dusts in air containing 7 per cent. of firedamp. Also, any explosion of dust is intensified by the presence of small proportions of firedamp in the mine air.

In 1886 the English Accidents in Mines Commission, after completing experiments and investigations covering a period of seven years, reported in substance as follows:

1. The occurrence of a blown-out shot in a working place where very highly inflammable coal dust exists in great abundance may, even in the total absence of firedamp, give rise to a violent explosion, or at least be followed by the propagation of flame over very considerable areas, and thus communicate flame to explosive mixtures in distant parts of the workings.

2. The occurrence of a blown-out shot where but a small percentage of firedamp exists in the air, in presence of but slightly inflammable or a wholly non-inflammable but very fine, dry, and porous dust, may cause an explosion, the flame of which may reach other distant accumulations of gas or deposits of inflammable dust, which in turn being inflamed thereby may extend the disastrous results to other more remote places in the mine.

An Austrian commission appointed in 1885 to investigate the causes of mine explosions, after conducting a large number of experiments with almost every possible kind and condition of dust, both with and without the admixture of gas, made a final report to the royal government in 1891 to the effect that nearly all kinds of coal dust were ignited by a cartridge of 100 grammes (.22 lb.) of dynamite lying loose. This small weight of explosive would of course correspond to a much heavier charge in proportion to the increased volume of the confined space where the explosion might occur. It was further found that the presence of but a small percentage of firedamp in the air manifestly increased the sensitiveness of the dust, so that a dust otherwise not dangerous may give rise to a disastrous explosion under these conditions. The fineness and the dryness of the dust, not to say the dryness of the air, was found by this commission to greatly increase the danger of inflammation.

The Royal Commission on Explosions from Coal Dust in Mines, commonly called the Royal Coal Dust Commission, appointed in England in 1891, in their second report in 1894, summarized the conclusions at which they had then arrived as follows:

"1. The danger of explosion in a mine in which gas exists even in very small quantities [proportions] is greatly increased by the presence of coal dust.

"2. A gas explosion in a fiery mine may be intensified and carried on indefinitely by coal dust raised by the explosion itself.

"3. Coal dust alone without the presence of any gas at all may cause a dangerous explosion if ignited by a blown-out shot or other violent [source of] inflammation. To produce such a result, however, the conditions must be exceptional and such as are only likely to be produced on rare occasions.

"4. Different dusts are inflammable and consequently dangerous in varying degrees, but it cannot be said with absolute certainty that any dust is entirely free from risk.

"5. There appears to be no probability that a dangerous explosion of coal dust alone could ever be produced in a mine by a naked light or ordinary flame."

132. **The Coal Dust Theory.**—Briefly stated the dust theory assumes that the fine dust of any combustible material held in suspension in the air and acted upon by a flame of sufficient volume and intensity is either itself consumed with explosive rapidity or distils gas that forms an explosive mixture with the air. When the dust is incombustible it may still assist the explosion of otherwise inexplosive gaseous mixtures by a catalytic action as will be explained (Art. 134). The theory assumes that the rapidity of the action and the force of the resulting explosion are in direct proportion to the fineness and inflammability of the dust. It supports the assumption that the fine dust of any combustible material under these conditions is explosive in an atmosphere that will support the combustion, whether gas is present or not. It is admitted, however, without argument that the presence of an inflammable gas in the smallest quantity both assists the ignition of the dust and increases the force of the explosion produced. On the other hand the presence of an extinctive gas retards the ignition of the dust, and reduces the explosive force, even to rendering the dust-laden atmosphere inexplosive by reason of its presence.

The essential factors of any explosion are the presence of a combustible in such form as makes combustion with explosive rapidity possible, the presence of an atmosphere that will support the combustion, and the maintenance of a degree of heat at least above the temperature of ignition of the combustible. Any condition whatever that lessens the effectiveness of any of these factors reduces not only the force of an explosion but the liability of its occurrence

133. The Percussive Theory.—The reasoning on which this theory is based has been offered from time to time as furnishing a satisfactory explanation of certain observed facts relating to the practically instantaneous transmission of the fatal effects of an explosion throughout a mine. The records of mine explosions abound with instances in which the fatal blast was felt with equal suddenness and violence in distant parts of the mine at the same time. Other recorded instances show the practically simultaneous explosions of gas in distant portions of the mine, isolated from each other by long stretches of roadways and air passages that were found to bear no trace of flame having passed through them. The percussive theory assumes that a wave of compression imparted to the air by the force of the initial explosion is transmitted almost instantly to other portions of the mine, where sufficient heat is developed by the resistance it meets to cause the ignition of other bodies of gas accumulated there. Experiments are quoted as proving that it is possible to cause a spark by the sudden compression of pure air in a glass cylinder by quickly forcing down a tightly fitting piston. Mr. Joseph Dickinson, Her Majesty's senior inspector of mines, Great Britain, stated in his evidence before the Royal Coal Dust Commission (1891), that he had with such a device struck a spark in pure air fifty times, but that he could never get a spark twice from the same air, it being necessary to recharge the instrument with fresh air each time. An instrument was devised on this principle, for the purpose of testing for firedamp in mine workings, by Dr. Angus Smith, who supposed that it required from 1 to 2 per cent. of marsh gas in the air to produce the spark, but this was found not to be the case. Whether or not this illustrates what takes place on a larger scale in a mine explosion can only be conjecture, but the percussive theory has gained many strong adherents, prominent among whom are Mr. Joseph Dickinson and Mr. James Ashworth.

134. **Character and Influence of Dust.**—Dust possesses both a chemical and a physical character, which affects its inflammability and in other ways also determines the extent to which it is a dangerous element when suspended freely in mine air. It has been shown by Sir Frederick Abel and others that the finely divided dust of certain incombustible substances as chalk and magnesia assists the explosion of otherwise inexplosive gaseous mixtures. This was at first attributed to the supposed action of the dust as a conductor of heat or some other form of energy, but later was explained as being due to a catalytic action of the dust on the gas and air. However this may be, the fact has been well established by the experiments of Dr. Broockmann, Manager of the Royal Prussian Experimental Laboratory at Bochum, Westphalia, and by the observations of the Messrs. W. N. and J. B. Atkinson, H. M. inspectors of mines and others, that coal dust, especially fine coal dust, absorbs a very considerable volume of oxygen from the air. The Messrs. Atkinson discriminate between what they term *upper* dust, or the dust accumulating on the timbers and the sides and top of airways, and *bottom* dust taken from the floor. It is claimed the upper dust, which is lighter and finer than bottom dust, undergoes a slow change by reason of which it is rendered highly combustible and easily inflammable, possibly due to the absorption of oxygen from the air, but doubtless owing

largely to the impregnation of the dust with the oily and sooty products of the incomplete combustion of inferior grades of illuminating oils burned in the lamps or torches in use on these roads, as well as the disintegrating influence of the atmosphere on the dust, and to the absorption of oxygen combined.

Under the favorable conditions presented in a mine the explosion of 1 pound of fine, inflammable coal dust suspended in the air and subjected to the flame of a blown-out shot or other explosion would produce a volume of carbon monoxide gas equal to 31.5 cubic feet, measured at 60° F., and a pressure of 14.7 pounds per square inch, and this gas disseminated in air would render explosive a maximum volume of 2440 cubic feet of the mixture, measured at the same temperature and pressure. It must be remembered that any carbon dioxide gas formed by an explosion in an excess of air may be again reduced by the intense heat of the explosion, in contact with unburned incandescent carbon (dust), to carbon monoxide (Art. 112), making possible the theoretical conditions mentioned above, which, however, could not be expected to obtain in any experimental test; but the possibility is clearly shown.

135. Phenomena of Mine Explosions.—These are varied, owing to the multitudinous conditions affecting the occurrence. In some instances the victims of a mine explosion have been stricken with death, as it were in a moment of time, without warning. Men have been found in postures that left no doubt of the utter absence of alarm; some in the act of eating or drinking, others with pick in hand engaged in mining the coal when the fatal shock came. At other times there is no sudden and violent shock, but a certain ominous disturbance of the air, followed quickly by a rush of wind bearing dust and debris. The presence or absence of flame and the degree of violence of the blast will be determined wholly by the conditions relating chiefly to the character of the initial explosion, the condition of the mine with respect to gas, dust, and moisture, the quantity of air in circulation at the moment of the explosion, and the volume and temperature of the workings, size of openings, etc.

In studying the phenomena of mine explosions of any considerable magnitude, it is important to remember that air (oxygen) is as necessary to flame, as a degree of heat sufficient to cause the ignition of fresh supplies of the combustible. In the narrow confines of the mine passages it is not only possible but highly probable that the projected blast of gas, dust, and other combustible material often traverses long distances at a temperature far above that required for ignition, but with little or no accompanying flame, being propelled by the powerful expansive forces being developed within the *cul de sac* of the workings. At some distant point in its path, or perhaps at the mine opening, the contact of the overheated gases with a sufficient volume of air causes a burst of flame. This condition is more apt to result from a dust explosion or a gas explosion in which dust plays a prominent part than from a simple gas explosion. It is evident that the mere absence of any traces of flame or burning does not prove conclusively, as is often claimed, that the main blast of the explosion did not pass that way. Again, the ignition and explosion of seemingly isolated bodies of firedamp in portions of the mine distant from the initial point of the explosion, and separated therefrom by a long stretch of roadway apparently unswept by flame, does not prove a second ignition from another cause. To explain such an occurrence it is not even necessary to resort to the theory of ignition by percussion (Art. 133), although this is entirely possible. Another possible cause of the ignition of such an isolated body of gas is the effect of the concussion produced in the air by the initial blast, upon the dust-covered lamps in other portions of the mine. The same concussion of the air acting simultaneously on a dusty lamp and the gas-laden air about it not only causes the lamp to *flash* (pass its flame through the gauze), but renders the atmosphere, for that moment, more explosive, owing to the increased pressure on the air. Any one of these three causes may produce the almost simultaneous ignition of bodies of firedamp that under ordinary conditions are isolated from each other. Separate explosion centers may be thus developed at different points throughout the mine when the conditions are favorable.

The effect produced by concussion, on air containing an ordinarily safe proportion of gas, by which an otherwise safe atmosphere is rendered momentarily explosive, and the simultaneous effect produced by the same cause upon lamps, should be a warning against the common practice of allowing but a slight margin of safety in respect to the gaseous condition of the mine air.

A peculiar phenomenon of some dust explosions is the *extinction of the flame* of the explosion by reason of the thick clouds of dust that fill the air and speedily consume all the available oxygen. The atmosphere under these conditions becomes a veritable sea of dust, which is found afterward covering the floor in certain portions of the workings to the depth of several inches. Men have been found under these terrible conditions with the mouth and nostrils packed tightly with the dust. The appearance of the ignited dust of a small, local explosion has been described by survivors as that of "a shower of red-hot sparks." Where dust has been present in an explosion in such quantities as to cause the extinction of the flame of the explosion, the thick deposits of dust found afterwards show a semi-coked condition, the particles of dust being partly rounded. The dust is also found upon examination to have lost a portion of its volatile matter; otherwise it is unchanged.

In regard to the *deposition of dust* on the timbers in a passageway traversed by the blast of an explosion there is a variance in the experience of different writers. In the report of Faraday and Lyell upon the Haswell Colliery explosion, to which reference has previously been made (Art. 131), it is clearly stated that the dust was deposited on those faces of the pillars, props, and walls in the direction of and on the side towards the explosion. The Messrs. W. N. and J. B. Atkinson in their book Explosions in Coal Mines, page 25, state: "The deposit of dust on timber and other things affords an indication as to the direction [of the blast], which the writers think is usually misinterpreted. . . . This matter was more fully investigated at Usworth than at any of the other explosions. . . . At Usworth observations were made in more than twenty instances. The direction of the blast was, in most of these cases, not a matter of any doubt whatever. It appears from these observations that dust either as dust or as coke is generally deposited on the sides of the props, etc., opposite to the direction of the blast."

The experience of the writer in the Cedar Mines explosion at Albia, Iowa, and in the Coal Creek explosion at Fernie, B. C., Canada, in both of which coal dust played a prominent part, would confirm the latter statement. In each of these cases the dust was found on the lee of the timbers, or on the side away from the blast. In this connection, however, it should be frankly stated that so manifold are the conditions relating to the blast, and the character of the deposited dust varies so widely in different instances, that it is not only possible but probable that dust may be deposited on either side of timbers, but will then have a somewhat different character in each case. In general the dust projected forcibly against the face of timbers or other obstructions in the path of a blast, and deposited thus on the side toward the blast, will be coarser and harder than that deposited on the lee of such timbers or obstructions. In any case, the thickness of the deposit and the coked condition of the dust will depend on the quantity of dust thrown into the air, its character, and the character of the blast. The coking of the deposited dust is often the effect of the return flame, which burns more quietly and is hotter than the original blast. It may happen that the same passageway is traversed, in opposite directions, by two distinct blasts, originating from isolated centers of explosion or by the flame due to the recoil of the original explosion, and the resulting phenomena must be judged in the light of these possibilities.

The extent to which *coking* is produced as a result of an explosion will depend on the force of the blast, the intensity of the flame, and the character of the coal and fineness of the dust. The process is the same as what takes place in the ordinary coking of coal; the volatile matters of the coal are expelled, leaving a hard, brittle, and more or less fused residue. When coke is formed it is found after the explosion deposited in most places where dust would be deposited, but generally in larger quantities on those timbers and faces of the coal more exposed to the action of the flame. Coking is evidence, at the same time, of extreme heat and a limited supply or the entire absence of oxygen in the atmosphere of the workings at the time of the coking of the dust.

The *recoil* or the *return flame* of an explosion, as it is often called, is an interesting phenomenon. As the first explosive blast sweeps through an entry or mine passage, it leaves behind it a trail of hot and generally inflammable gases, consisting chiefly of carbon monoxide and nitrogen. The immediate cooling of these hot gases causes a depression or fall of pressure in the entry, and, as a consequence, air rushes in from the adjoining rooms or chambers and other workings. Thus a fresh supply of oxygen is furnished, and the flame having been arrested in its advance by the increasing effect of the depression behind or by its own expansion and cooling, or other cause, starts to burn back on its own trail. This second burning is less rapid and violent but generally hotter than the first blast, and often reaching lower down from the roof, even perhaps lapping the floor. Most if not all of the available oxygen of the mine air is now consumed, and naught remains but the deadly afterdamp. In special cases where more air finds its way to the place, a third but feeble burning may result, which, however, is rare.

136. Entering a Mine After an Explosion; Rescue Work.— The difficulties and dangers of this work will depend much on the conditions with respect to the character of the mine and the magnitude of the occurrence. Prompt, intelligent action is required on the part of those outside of the mine, upon the first intimation of trouble below ground, and it is likewise necessary that any survivors in the mine should display the same promptness, coolness, and intelligence in their own behalf. Excitement is almost certain to result fatally, because an exhausted condition of the body, and particularly of the lungs, cannot long survive a rapid transition from breathable air to an atmosphere of afterdamp. It is a matter of record that in numerous large mine explosions from 85 to 95 per cent. of the victims have been killed by inhaling afterdamp. As suggested by Dr. Haldane in his report to the English government on the causes of death in colliery explosions and underground fires, many lives would often be saved if the men remained in their working places instead of rushing out on the airways, where certain death awaits them. In this it will be necessary to be guided by sound judgment based on an accurate knowledge of the movement of the air and the location of the explosion. It would be courting death to attempt to escape by an intake road if the force of the explosion came from the direction of the shaft or mine opening. In such a case the only hope of flight would be by a possible circuitous route following the return air. If this is not possible, safety should be sought in some isolated district of the mine or section of the workings that may be sealed off, and here, with lights out and lying on the floor, assistance from the outside should be awaited.

On the surface, a speedy call having been made for volunteers and medical assistance, the ventilating apparatus is hastily examined and any necessary repairs promptly and quickly made. It is important to observe closely the effect produced by the explosion on the general circulation of the mine as revealed by the condition of the upcast or return air discharged from the mine, and the quantity of air entering the mine. The explosion may have destroyed the circulation so that practically no air is found entering the mine, or the current may even be reversed.

While this is being done the safety lamps, tools, and materials that will be required in the mine are prepared and brought to the entrance, where they will be in readiness for use. From among the volunteers only the most experienced and tried men should be chosen to enter the mine. No one who is subject to heart trouble should be chosen for this work. The rescue party thus formed is divided into two squads or divisions, the one to act as an advance or exploring party, and the other to follow as closely as possible, completing the temporary repair work of the first party and rendering all needed assistance to hasten their progress.

The mine must be entered by the intake opening, and *no advance must be made ahead of the air-current.* Each party is placed in charge of a competent and experienced person who is thoroughly familiar with the mine. Having entered, the first party proceeds as rapidly as the circumstances will permit to explore the mine. Air-stoppings, doors, brattices, and air-bridges have often been blown down and must be replaced temporarily, or some form of brattice constructed to carry the air-current forward. The work of this kind performed by the first or exploring party is of the most temporary nature, and is completed by the second party following. The air-current is thus strengthened against the accumulating afterdamp, which must be slowly forced out of the roads into the return airway to permit the rescuers to advance. The greatest caution is required to guard against roof falls, the ignition of firedamp that may have accumulated since the explosion took place, and the even greater danger of being overcome with the deadly afterdamp. In places the entry may be completely or partially blocked by high falls of roof, which must be passed over, as there is not time for their removal. The lamps must be carefully watched, especially on top of the falls, to ascertain the gaseous condition of the air at all points of the passages traversed by the rescuers.

Owing to the fact, however, that lamps will continue to burn in an atmosphere that is fatal to life (Art. 118), it is necessary to observe more carefully one's breathing, pulse, and general feeling. In the presence of poisonous gases, particularly carbon monoxide, a rapid pulse and more or less labored breathing is quickly followed by a weakness of the limbs that in most cases produces immediate prostration and utter helplessness or inability to move. It was want of this knowledge that led to three of the explorers' lives being lost after the explosion at Penygraig in 1880. When the leader of the explorers was advised to return from the afterdamp, the last words he is known to have said were that while the light would burn he could live. A curious effect of afterdamp is that when a strong man has worked until he feels weak, he becomes partly intoxicated and talkative. It is time then to return, and when such a man reaches pure air he is sure to fall unconscious. A good safeguard against being overtaken unawares by the poisonous afterdamp is to carry along a caged mouse, which will show signs of prostration from the effects of the gas and thus give ample warning in time to withdraw to better air (Art. 92).

The symptoms of gas poisoning and the treatment of persons overcome by gas has been fully explained in the chapter on Mine Gases. Victims of gas poisoning should not be removed too quickly from the atmosphere of the mine to the outside air. Violent delirium often results when the patient is brought to the surface too rapidly, or a strong man who has withstood the effects of the gas for a long time in the mine may fall unconscious on reaching the surface. The loss of consciousness in the latter case is possibly due to a diminished flow of blood to the brain the result of being hoisted to a higher and lighter atmosphere, or to a change in the hygrometric condition of the air.

There should be kept on hand at every mine such an emergency outfit and such simple remedies and needed supplies, splints, bandages, etc., as are liable to be required for the immediate treatment of broken bones, burns, or scalds, or persons overcome by gas, or suffering from shock or loss of blood. There should be a good proportion of the men distributed through the mine who have more or less training and knowledge in regard to what is necessary to be done to save life in case of accident, while a specially trained corps of assistants should always be available on the surface at the mouth of the mine. The necessary ambulance outfit, including suitable stretchers, blankets, and rubber coverings, should be always at hand and ready for use. Special rescue apparatus such as head coverings (Fig. 15) of different styles, together with tanks or bags charged with compressed air or oxygen and worn or carried by the user, have been employed with much success, but ordinarily the mine passages are too badly blocked to permit of the employment of a helmet such as shown at (*a*).

The Courrières disaster—France (1906)—has drawn attention very forcibly to the use of **breathing apparatus** in rescue work in mines. The observations and conclusions of Dr. G. A. Meyer, Westphalia, who organized and conducted a special rescue corps and rendered efficient service in the examination of the Courrières mine, after the explosion, are of particular value. In a paper recently contributed to The Institution of Mining Engineers,*

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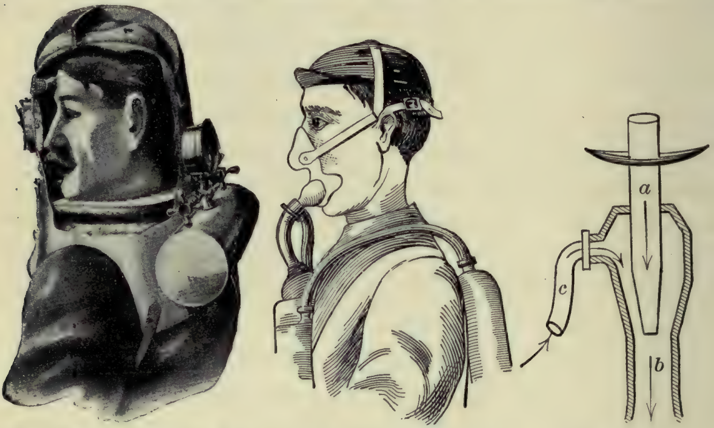
* Trans. Inst. M. E., Vol. XXXI, p. 575.

Dr. Meyer describes the essential requisites of breathing apparatus suitable for mine rescue work.

The earliest form of breathing apparatus was designed (1853) by Prof. Theo. Schwann, Professor of Physiology at the University of Liège, on the general principle established by Regnault, namely, that the *vitalizing power of air depends only on the removal of the carbon dioxide from the air expired from the lungs, and replacing the oxygen consumed in the oxidation of the impurities of the blood.* Air thus purified can be respired continuously without danger to the system.



(*a*) Vajen-Baden Helmet (*b*) Shamrock (Meyer) Apparatus (*c*) Detail of Mouthpiece

FIG. 15.—Breathing Apparatus—Rescue Work

It is estimated * that an adult in usual good health respires, at rest, 263 cubic centimeters of oxygen per minute or 15.78 liters per hour, and very violent exertion increases this amount about eight or nine times. This estimate is confirmed practically by a long series of experiments per-

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* Investigations on the Supply of Air and the Conversion of Energy in Cyclists.—Dr. Leo Zuntz, Berlin.

formed in the Shamrock Mines, Westphalia, which showed that a miner in the ordinary performance of work consumes practically 2 liters of oxygen per minute, corresponding to a respiration of, say 600 cubic inches of air each minute. These figures have formed the basis of the calculation for determining the necessary size of the oxygen cylinders of a breathing apparatus. The best forms of breathing apparatus are supplied with two oxygen cylinders, one of which is for use on the in-going trip in a mine, while the other is held in reserve for a safe return to fresh air. The oxygen is compressed to 120 atmospheres, which multiplies the capacity of the supply cylinders in the same ratio. On this basis each liter of tank capacity permits of an hour's use of the apparatus.

The regeneration of the air was first attempted by the use of hydrated peroxide of barium, which was expected to absorb the carbon dioxide and liberate oxygen at the same time. The amount of oxygen set free, however, was found to be insufficient and some ozone was formed. Later this absorbent was replaced by hydrated lime saturated with a solution of caustic soda, which gave better results and is still used.

The type of apparatus recommended by Dr. Meyer is that shown at (*b*), Fig. 15, in which the oxygen is inhaled through a tube held firmly in the wearer's mouth. A nose clip is attached to the upper side of the tube and two plugs of cotton wool soaked in vaseline are so arranged as to close the nostrils completely. This mouthpiece, shown in section at (*c*), is an important feature of the apparatus. It is constructed on the principle of the injector, so as to prevent as far as possible the inhalation of expired air that has not passed through the regenerator. The exhaled air passing through the nozzle *a* is conducted by the tube *b* to the regenerator worn on the chest. The discharge of the exhaled air through the nozzle *a*, causes a depression or partial vacuum in the tube *c*, conducting fresh supplies of air to the mouth. The chief problem lies in the removal of the carbon dioxide from the air by bringing the latter into regular contact with the caustic alkali contained in the regenerator. The circulation of the air through the apparatus must be accomplished without making any demand on the respiratory muscles. The apparatus requires about 2¼ pounds of the alkali every two hours.

The experimental observations of Dr. J. S. Haldane and Mr. J. Lorrain Smith, led to the following conclusions: (1) Respiration becomes noticeably more difficult when the proportion of carbon dioxide in the air exceeds 4 per cent., by addition; that is to say, when the oxygen of the air is not depleted. (2) The continued breathing of air containing more than 4 per cent. of carbon dioxide causes headache and throbbing, followed by nausea. (3) No ordinary excess of oxygen avails to overcome these effects produced by an excess of carbon dioxide. (4) An insufficient supply of oxygen (excess of nitrogen) in the air breathed causes a difficulty in respiration, which first becomes noticeable when there is but 12 per cent. of oxygen present. There is excessive difficulty and a sense of suffocation when the oxygen falls to 6 per cent.

137. Mine Hospitals, Refuge Stations, etc.—Every large well-equipped mine is now provided with a suitable and comfortable hospital room underground (Fig. 16), where any who may be injured or overcome by gas can receive prompt treatment under favorable conditions. These hospital rooms are supplied with hot and cold water, good air, and means of regulating the temperature as required. In some cases they are provided with beds, lighted by electricity, and heated by steam.

Since so large a number of the deaths resulting from mine explosions are due to inhaling afterdamp, every practicable means of avoiding this should receive careful attention. In this connection it was suggested some time ago that in all fiery and dusty mines there should be provided in the mine workings, approved stations, which should be connected with an air-compressing plant on the surface by adequate pipe lines for supplying sufficient air to keep alive a large body of men who might find their way to such station, in case of accident shutting off the avenues of escape and destroying the circulation of air in the mine. It was suggested that the pipes for the

Fig. 16.—An Underground Hospital

supply of air should be laid just beneath the floor of the mine roads to protect them against roof falls. The end of each pipe line should be provided at each station with a tap, which should be kept closed, and opened only by those occupying the station at the time of accident so as to insure the proper use of the air. The writer would only add to this valuable suggestion that each safety station should be reached by drill holes sunk from the surface, a single hole for each station, of sufficient size for passing food and water to the imprisoned men. The supply of air should be sufficiently strong to drive back the damp from entering the enclosed area. If the provision of such refuge stations in fiery and dusty mines should prove efficacious in a single instance in a decade of years it would have earned its right to be considered always afterwards as a necessary feature of such mines.

138. Record of Recent Disastrous Mine Explosions. Some of the more disastrous explosions that have occurred in this country during the past ten years are tabulated here, because, to the best of the writer's knowledge, there exists no authentic record of such catastrophes in America, and because of the impressiveness of such a record, and with the hope that it may assist to stimulate efforts looking to the adoption of remedial measures both in needed legislation and mine management. In England and on the Continent more attention has been given to the subject by the several governments of the states where the work of mining is carried on; and properly authorized commissions have been appointed at different times in England, France, Belgium, and Austria to investigate the general subject of mine explosions, and to determine, as far as may be possible, by experiments performed on a large scale and at great expense, the nature of the explosion of gas

TABLE 22

LIST OF MINE EXPLOSIONS OFFICIALLY REPORTED IN THE UNITED STATES AND CANADA, NUMBERING 5 OR MORE FATALITIES, SINCE JANUARY, 1896

Date	Place	Fatality
1896, Jan. 23	Newburg, W. Va.	39
March 23	Berwinsdale, Pa.	15
Oct. 29	So. Wilkes-Barre, Pa.	6
1897, Jan. 4	Alderson, Ind. T.	5
1898, Sept. 23	Brownsville, Pa.	8
1899, July 24	Grindstone, Pa.	5
Dec. 23	Sumner, Pa.	20
1900, March 6	Red Ash, W. Va.	46
May 1	Scofield, Utah	200
Nov. 2	Berryburg, W. Va.	15
1901, April 29	Alderson, Ind. T.	6
May 15	Chatham, W. Va.	10
27	Richland, Tenn.	20
June 10	Port Royal, Pa.	19
Oct. 26	Diamondville, Wyo.	32
Nov. 14	Pocahontas, W. Va.	9
22	" " "	8
1902, Jan. 24	Lost Creek, Ia.	20
March 31	Dayton, Tenn.	16
May 19	Coal Creek (Fraterville), Tenn.	184
23	Fernie, B. C., Can.	127
July 10	Johnstown (Rolling Mill mine), Pa.	112
Sept. 16	Algona, W. Va.	17
22	Stafford, W. Va.	6
1903, April 13	Carbon, Ind. T.	6
Nov. 21	Ferguson, Pa.	17
1904, Jan. 25	Cheswick (Harwick mine), Pa.	178
March 6	Catsburg, Pa.	5
Oct. 28	Tercio, Col.	19
Nov. 29	Luke Fidler, Pa.	7
1905, Feb. 20	Virginia City, Ala.	116
26	Bluefield, W. Va.	23
March 18	Red Ash, W. Va.	24
22	Princeton, Ind.	9
April 3	Zeigler, Ill.	53
20	Cabin Creek, W. Va.	6
28	Dubois, Pa.	13
30	Wilberton, Ind. T.	13
July 5	Vivian, W. Va.	10
Oct. 13	Frederickstown, Pa.	6
Nov. 4	Vivian, W. Va.	7
15	Bentleysville, Pa.	8
Dec. 1	Diamondville, Wyo.	18
1906, Jan. 4	Coaldale, W. Va.	22
18	Detroit, W. Va.	18

TABLE 22—*Continued*

Date	Place	Fatality
1906, Jan. 24	Witteville, Ind. T.	14
Feb. 8	Parral, W. Va.	27
19	Maitland, Col.	16
27	Piper, Ala.	9
March 22	Century, W. Va.	21
April 21	Trinidad, Col.	22
June 6	Red Lodge, Mont.	8
July 19	Huger, W. Va.	5
Oct. 3	Pocahontas, W. Va.	37
5	Blossburg, N. Mex.	15
24	Johnstown, Pa.	7
1907, Jan. 23	Primero, Col.	20
29	Fayetteville, W. Va.	75
Feb. 4	Elkins (Thomas mine), W. Va.	38

and dust separately and combined. It is to the work of these commissions that we owe the most of our present knowledge of explosive conditions in mines. Table 22 is a partial list of the fatal mine explosions that have been officially reported since January 1, 1896, as causing the deaths of at least 5 persons. That such a list shows but a small portion of the actual fatalities and a still smaller portion of the total number of explosions occurring is evidenced plainly by the reports from any one of the states. For example, in the Indian Territory alone, where a careful record has been kept during the last ten years, the reports of the U. S. Mine Inspector show that a total of 174 explosions occurred, of which but 61 were fatal, causing the death of 117 persons. Of this large number of catastrophes in a comparatively small mining district but 4 explosions, causing in all 30 deaths, appear in the table. In this connection it is well to remember that the number of fatalities is but an incident in the occurrence of an explosion, the occurrence itself being the main fact, which may or may not be accompanied with great fatality according as persons are or are not at hand. The fatality of an explosion depends further on the conditions of environment.

139. Prevention of Mine Explosions.—A strict enforcement of the mining law of the state in which the mine is located, and of the regulations in force at each mine, together with a *rigid discipline and eternal vigilance* on the part of officials and miners alike, will result in a degree of immunity from these dread happenings in proportion to the intelligence of all concerned, with respect to the occurrence, behavior, and properties of mine gases. This knowledge is as necessary to the making of proper laws and regulations as it is to the safe performance of the work in the mine. Though with the utmost of care it may not be possible to obtain absolute freedom from accidents of this nature, yet the evil can be greatly ameliorated by the careful and intelligent consideration of the conditions in any particular mine with respect to the character of the coal, the gaseous condition of the seam, the method to be adopted for the extraction of the coal, and other like factors. The following general remarks will serve to suggest precautionary measures that should be considered in order to render the operations of mining reasonably safe.

Care must always be taken to avoid the accumulation of gas, by maintaining an ample and efficient circulation throughout the workings. The air-current must be made to sweep all cavities or other void places that form lodgments for gas, and the velocity of the air must be sufficient to effect the removal of the gas as fast as it issues. Abandoned areas left standing open may form dangerous reservoirs of gas unless these are thoroughly ventilated by an air-current made to pass constantly through them. Often the best means of keeping such abandoned places free from dangerous accumulations of gas is to sink one or more 4-inch bore holes from the surface so as to tap the gas at the highest point in this area. This has been found to give immediate and permanent relief by draining off all the gas that would otherwise accumulate in such places and endanger the mines.

In the working of soft, inflammable coal every means practicable should be adopted to reduce to a minimum the breaking up of the coal and the formation of fine dust. Where machines are used to mine the coal, and particularly where coal is blasted, the accumulations of fine coal and dust should be removed regularly from the roads and from the working places. The **watering or spraying** of the working face and the roads leading thereto previous to firing a shot clears and cools the air and lessens the quantity of dust that will be thrown into the air by the force of the blast just in proportion to the thoroughness of the watering. To the same extent, also, is the spraying of the mine haulways efficacious. Too much reliance should not be placed on watering; there is no ground for the belief that any practicable amount of watering of the mine passages and workings will or can avail to stop any mine explosion after it has once gained headway. Any system of watering practicable in a mine can only lessen the tendency to an explosive condition of the air by clearing the mine atmosphere and reducing to a minimum the quantity of fine dust thrown on the air-current by the operations of the mine. It is also possible that the moist condition of a mine induced by injudicious watering may even prove, under certain conditions, an evil instead of a benefit.

Mr. James Ashworth, in commenting on the experiments performed by Mr. Henry Hall, Inspector of Mines for the

Liverpool district, England, draws attention to the fact that some of the most violent explosions Mr. Hall obtained occurred when rain had been falling nearly all the day, and the air lacked but .6 grain of saturation, the temperature being 52° F. The moisture in the air was, therefore, 87 per cent. of the amount required for saturation. The flame of the explosion in this case was projected 60 feet into the air, above the top of the shaft. Mr. Ashworth, who has given much thought to this subject, states that the safest possible atmosphere for mine work would be one that was *absolutely dry;* but, since this is a practical impossibility, he concludes that when the conditions are such as to render blasting dangerous, a *working place* should be made "soaking wet" before firing, but elsewhere in the mine only sufficient water should be used to clear the air of the fine dust raised by the ordinary operations of the mine and borne in suspension on the air-current. Briefly, the safest condition with respect to fine inflammable dust held in suspension in the mine air is not to be sought in abolishing the use of water for the purposes of spraying, for this would not insure the "absolutely dry" atmosphere that Mr. Ashworth advocates as the "safest atmosphere for mine work and blasting." Indeed it is practically impossible to realize such an atmosphere in the driest quarters of the earth's surface, much less in underground workings. Since, then, water must always be present in the mine air to an extent that will make possible the explosion of fine inflammable dust, relief and safety must be sought in applying a sufficient quantity of water to clarify the air traveling on the roads, and render it safer in presence of gas, and more wholesome to breathe. The working face in the vicinity of a blast should be made thoroughly wet before firing a shot; the quantity of water used should be in proportion to the fineness and inflammability of the dust.

Under the dangerous conditions just described, the most practicable plan for the spraying of a large mine may be to run a pipe line the entire length of the haulways from the shaft bottom to the heads of the several entries. Arrangements should be made to reach the face of each chamber or working place, either by means of branch pipes of less diameter or by a sufficient length of hose that can be attached to plugs in the main pipe on the entry. At suitable intervals along the haulways, which should be determined by the conditions in the mine, a jet spray or sprinkler should be attached permanently to the main pipe and kept open continuously during working hours.

One of the most pernicious practices in the working of a gassy seam, and a practice seemingly authorized by custom, born of the willingness of the miner to assume risk, and of his thoughtlessness for himself and others, and in part of his ignorance, is the practice of allowing the use of **mixed lights.** From long and close observation it is the writer's conviction that this seemingly guarded practice is responsible for mine disasters to a greater extent than any other contributory cause. Under certain conditions judged to be safe by the fire boss, and with the full knowledge of other mine officials, the miner, though furnished with an approved form of safety lamp by the company, is permitted to take into the mine with him his own common lamp, which he uses according to his own sweet will, only to receive a sharp reprimand from the boss were that individual to make an unexpected visit to his place and find him thus. At another time, with the knowledge of the boss if not with his permission, the *safety lamp* is hung on a convenient post near to the roof to keep the miner informed (if he looks that way) of any increase in the body of gas above him. Thus guarded the miner with his *open light* set on the floor undermines the face of coal and prepares a shot with an abandon of any thought of danger that would be truly heroic if performed for a noble purpose. Though a criminal offense under the state law, the writer has seen men with a full knowledge of the law and with reasonable intelligence but lack of regard for their own safety or that of any one else in the mine, pass a plain danger board marked "Gas" and proceed to work with their open lights within 10 yards of a large body of firedamp, sufficient to have wrecked a good portion or the whole of the mine. Such is the seemingly approved recklessness of the average miner because of his familiarity with danger.

The enactment of law and the punishment for violation of mine regulations are powerless to meet this exigency; nothing but eternal vigilance on the part of mine officials and an honest regard for the safety of human lives can serve to avert the evil results of such reckless disregard of danger. As long as the use of mixed lights is sanctioned by mine officials, there will continue the same reckless disregard for the mine regulations on the part of the miner, because he considers his judgment equal to that of the fire boss, and is willing to take the risk. But the unguarded raising of his lamp too near the roof, or an unexpected agitation of the air, caused, it may be, by a slight fall of slate or coal, ignites the gas, which may result in a serious explosion. It is a foolish and dangerous practice to light a thin layer of gas at the roof of a well-ventilated chamber for the sport of seeing it burn or for the purpose of getting rid of the gas. The quiet burning of the gas may at any moment under the slightest provocation develop into a serious explosion.

The use of **electricity** in any form or for any purpose should not be tolerated in a gaseous mine. Under the varied conditions of mining the risk of the ignition of firedamp by the sparking of wires or brushes, the burning out of a fuse, or the breaking of a lamp, or other cause is too great to be assumed by a responsible management.

140. Relation of Blasting to Mine Explosions.—It will not be denied that blasting in mines is a prolific cause of the explosion of gas and dust in the workings. While this is due in part to carelessness in the manner of firing the shot, and in part to inexcusable ignorance in regard to some of the simple principles of blasting, yet much of the trouble must be attributed to a lack of knowledge, on the part of the shot-firer, of the tremendous energies that are locked up in the gas- and dust-laden air about him, even exceeding by many times the energy of an equal weight of the powder itself. For example, the energy of a single pound of methane (marsh gas) mixed with air exceeds that of a 25-pound keg of common black blasting powder, while the energy of the same weight of carbon in the form of fine dust is slightly more than half this amount. These energies, expressed in foot-tons, have been given in Table 21. It is then only a question of setting free the great energies that lie dormant in the stores of combustible matter on every hand, in the mine, and the result is a mine explosion. The wonder is that the action once started ever ceases, the mine becoming a furnace in which the heat and the pressure due to the combustion are largely confined. The mine itself forms an immense *cul de sac* that greatly intensifies the results, till the lack of oxygen alone puts an end to the chemical activities.

When a shot blows its tamping instead of breaking down the coal, a portion of the energy of the charge is expended on the air. A sheet of flame is projected with much force from the hole, producing a great commotion in the air and raising a cloud of fine dust, which is at once converted into gas and expands with explosive force. Under certain conditions in narrow and contracted workings the action is accumulative and what takes place on a small scale in such a chamber or heading is duplicated on a far greater scale through the mine, in a mine explosion. The point to be remembered is that the heat and the pressure incident to blasting in a confined or contracted chamber or heading may easily reach the danger point when the temperature of the air in the immediate vicinity of the shot will be sufficient to start fresh chemical activities. The danger is much increased by the presence of fine dust floating in the air, and is not wholly dependent on the inflammability of the dust (Art. 134), though greatly augmented thereby. The presence of even the smallest quantity of gas in the air other than the gases produced by the explosion of the powder adds to the danger of the ignition of the dust if the latter is combustible.

A **blown-out shot** furnishes the necessary volume and intensity of flame required for the ignition of gas and dust, or even of dust alone in the entire absence of gas except such as is produced by the burning of the powder, provided the dust is combustible. The danger arising from fine incombustible dust floating in the air can only exist when gas is present. The influence of such dust in assisting the explosion of gaseous mixtures has been explained as being due to what Berzelius has called *catalysis*, or decomposition by contact. There is yet much to be learned in regard to this action of fine incombustible dust, but little doubt exists of its influence being to increase the danger of ignition in a gaseous atmosphere.

A **windy shot** differs essentially from a blown-out shot, which does not break down the coal, but simply blows out the tamping. A windy shot, while it performs the work intended, expends a portion of its energy on the air, because the charge was in excess of what was required to break the coal; the shot was miscalculated. A similar effect is also produced sometimes when two shots are fired in rapid succession in a close place where the air is to a certain extent confined. Neither of the shots probably, if fired alone, would have caused any trouble; but fired in rapid succession the flame of the second shot is projected into an already overheated and overcharged atmosphere, laden with a considerable percentage of combustible gas and dust—the result of the first shot. As a consequence a local explosion takes place, which produces at least a heavy concussion of the air in the adjoining workings.

It is a dangerous practice to lay two shots that are intended to be fired at the same time, so that they will face each other more or less directly or shoot across each other; and there is some danger, which may often be avoided, in laying a shot so as to face a strong air-current in an airway. The heat energy developed at the moment of explosion is greatly augmented by the momentary arrrest of a ton or more of air traveling at a velocity of, say 600 feet per minute, representing practically 600 foot-tons, or say 1,500 B.T.U., in addition to the necessary heat of the charge. The heat energy of 1 pound of ordinary black blasting powder (Table 21) is 360 foot-tons, and for a normal charge of, say 6 pounds of this powder, the heat energy would be 6 × 360 = 2,160 foot-tons, or say 5,500 B.T.U. In such a case the effect of shooting against the air in this airway, in blowing down roof or lifting bottom, would be to increase the heat energy imparted to the air at the moment of the explosion more than 25 per cent.

Many attempts have been made and much labor and money expended to discover an **explosive** that would be safe to employ in gaseous mines. It is commonly agreed that while the different grades of black blasting powder, owing to the *gradual* development of the full explosive force, are best adapted to breaking down the coal in suitable shape for loading, yet the flame that always accompanies the explosion of this powder renders it an unsafe explosive to be used in the presence of gas. In seeking to minimize or wholly overcome this evil, if possible, recourse was had to different methods. Certain inert substances were introduced into the composition of the powder, such as sulphate of magnesia, the carbonates of sodium and calcium, to reduce the activity and absorb heat from the gaseous products of the explosion. Another method was to introduce nitrates into the composition of the powder to such an extent as to render the gaseous products of the explosion as nearly as possible incombustible. These highly nitrated powders are the famous Sprengle or so-called *flameless* powders. No powder, however, is absolutely without flame. Another method tried was to surround the explosive charge with water; this was known as the *water cartridge,* and was found by the experiments of the Accidents in Mines Commission (1881) to greatly reduce the risks of shot-firing in the presence of gas. In other experiments by the same commission wrought iron cylinders of the diameter of the bore hole and containing condensed (liquefied) carbon dioxide were placed over the charge in the hole for the purpose of extinguishing the flame of the blast by the liberation of carbon dioxide gas in large quantity. These methods, however, while they reduced the risks, offered no certain immunity from the danger due to the flame of the explosion.

In the following table are given the computed maximum temperatures resulting from the explosion of some of the more common explosives used in blasting. These temperatures are given here as suggestive of possible conditions with respect to the use of these explosives in mine work and for the sake of comparison.

TABLE 23

COMPUTED AND ESTIMATED TEMPERATURES OF EXPLOSION OF VARIOUS EXPLOSIVES

Explosive	Computed Temperature of Explosion, Deg. (Fahr.)	Estimated Temperature of Explosion, Deg. (Fahr.)
Gunpowder	6,100	4,000
Black blasting powder	4,400 (average)	3,000 to 3,600
Nitroglycerin	9,900	5,700
Guncotton	6,768	5,745
Blasting gelatine	....	5,828
Dynamite	....	5,260
Tonite	....	4,798
Roburite	....	3,812
Carbonite	....	3,352

The **detonating explosives,** as dynamite, guncotton, blasting gelatine, carbonite, gelignite, and others having nitroglycerin for a base, or ammonite, roburite, etc., having ammonium nitrate for a base, or the picric acid compounds, as lyddite, melenite, etc., all possess such a rapid and powerful action that the high temperature common to the explosion of powder is, in their case, maintained but for a slight fraction of a second, a time far too small for the ignition of pure firedamp (Art. 127). Unfortunately, however, firedamp as found in the mine is rarely if ever pure, being mixed in varying proportions with other hydrocarbon gases, sulphureted hydrogen, or olefiant gas, or contaminated with the fine floating dust of a highly inflammable coal, all of which lower the ignition point of the mixture. There is besides, in the explosion of some powders, a shower of projected, incandescent particles of combustible matter, coming mostly from the coal powdered by the force of the explosion, but in part from the powder itself. The heat of these burning particles is of sufficient intensity and duration to ignite any firedamp present.

The risks incident to blasting in the presence of **gas** are reduced to a minimum only when every possible precaution is taken to prevent the ignition of the gas that in some cases maintains a constant flow and cannot be sufficiently diluted with air, at the face of a breast, to prevent its ignition. The ventilation of such a breast must be arranged so that an accumulation of gas cannot occur as long as the current is maintained, which will insure the workings against an explosion, should the gas be ignited at the face, by the flame of a blast or otherwise. The means adopted for tamping and firing the charge and the method of lighting the same is of much importance in this connection. **Electric firing** must always present a far greater degree of security than firing by **fuse** or **squib,** and the latter should never be considered under the conditions named. An approved form of **touchpaper**—a paper that has been treated with a weak solution of saltpeter and dried, should be employed to ignite the fuse, which when used should be the best quality of double-tape fuse. The method of igniting the fuse by a **fine wire** heated to redness by inserting it through the meshes of the gauze of a safety lamp is dangerous, both as being liable to injure the gauze, and to ignite the gas by its own heat. The wire is, of course, small and does not retain its heat long, but its temperature ranges from about 1,000° F. when it first begins to glow red in the dark, to 2,370° F. at a white heat; the temperature of the wire at a dull-red heat is 1,290° F., which is above the ignition point of pure firedamp (1,200° F.). A charge should never be tamped with any combustible material; sand or the powdered clay taken from the roads and moistened makes a good tamping. A small ball of clay should be carefully pushed home over the charge first and the stemming or tamping rammed harder as the hole is filled. The practice of using powdered coal or slack for stemming is dangerous.

The **firing** of shots in a mine should begin on *the last* or *the end of the air* and proceed toward the intake, so that the gases produced by the first shots fired will be carried away from the vicinity of later shots. By this means not only do the shot-firers work in pure air, but the risk is avoided of the heated and combustible gases produced increasing the explosive condition of the air passing the face where shots are being fired. The air at the face during firing time should be pure and its temperature normal, that is to say, neither cool nor hot, since both of these conditions increase the danger. A large volume of pure air traveling at a moderately low velocity is the ideal condition that should prevail throughout the workings during and immediately preceding the time for firing, whether or not gas is generated in the mine.

The **slowing of the fan** or in any manner reducing the circulation *at* or *just previous* to the time of firing is a dangerous practice. The Mine Inspectors' Reports for Iowa * give two instances of fatal explosions that occurred where this practice was in vogue. In the latter case the report reads: "The ventilation in the 5th and 6th south entries was generally good, but as at the request of the shot-firers the fan was stopped when the miners were leaving the mine, there was little if any air moving at firing time." The argument used in support of this practice is briefly as follows:—A large volume of air means an increased supply of oxygen, which is the necessary fuel for an explosion, should one be started by the flame of a windy or a blown-out shot.—Granting this for a moment, is it not true that the reduction of the air-current at firing time permits the accumulation in the mine air of an even more dangerous *fuel* in the form of an increased percentage of carbon monoxide produced by the explosion of the powder, which with the fine dust blown into the air rapidly increases the explosive condition of the air? The air-current in its weakened condition and staggered by each succeeding blast is no longer able to oppose the expansion of the gas- and dust-laden air, which is forced back into the adjoining breasts and chambers where shots are yet to be fired. Could anything be more dangerous? Would any practical mining man hesitate for an instant in the choice between such an atmosphere of heated, dust-laden, and combustible gases and the pure air of a moderate intake current having a normal temperature? The argument for reducing the air at firing time is not strengthened by the statement that a dust explosion always advances and feeds on the intake air. It could do no otherwise than to

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* Tenth Biennial Report of the State Mine Inspectors, Iowa, page 54. Twelfth Biennial Report of the State Mine Inspectors, Iowa, page 23.

feed outwards, since the narrow confines of the inner workings are quickly stopped to the passage of flame by the products of the combustion. Let this practice cease, that no more lives be sacrificed to a foolish misconception of mining conditions.

141. Relation of Atmospheric Conditions to Mine Explosions.—The atmospheric conditions that affect or are commonly supposed to affect the occurrence of mine explosions are those relating to the pressure, temperature, and hygrometric condition of the atmosphere. The earnest desire of many investigators and practical observers to safeguard the work of mining by every possible means that science could suggest has no doubt led some to overestimate the effect not only of atmospheric conditions, but of all the causes suggested as in any way contributing to produce an explosive condition of the mine air. The true significance of barometric changes in relation to the occurrence of mine explosions has been much misunderstood, owing chiefly to the unguarded statements of some writers. The misapprehension thus caused in the minds of men charged with the conduct of mining operations has led too often to an utter disregard for the barometer and its indications.

The effect of a sudden fall of **barometric pressure** varying, say from one-half to one inch in from 6 to 12 hours is quite generally conceded to be followed, or it may be accompanied, by an outflow of gas from all standing areas and abandoned places in mines; there is also naturally an increase of gas on the falls and in proximity to large faults. Gas that has accumulated above a roof slate is likewise affected, and doubtless in many such cases the immediate result is the removal of from 50 to 75 pounds of support per square foot from beneath, which in effect adds this amount to the weight of the slate and invites falls of roof in the old workings, thus increasing the amount of gas set free. Some assert that there is besides an increased transpiration of gas from the solid face of the coal due to the decreased atmospheric pressure; but the rate of transpiration is not appreciably affected by any possible fall of the barometer, since the pressures under which gases are occluded, which is estimated by eminent authority to be as high as 3,000 pounds per square inch, are too great, as compared with atmospheric pressure, to be affected appreciably by such changes.

As Mr. A. R. Sawyer has remarked, and the statement is warmly supported by Sir Frederick Abel,—It is idle to attempt to establish or prove that there is or has been any fixed relation between such barometric changes and the occurrence of mine explosions. Two reasons show at once the futility of such attempts: First, in all well regulated mines the slightly increased outflow of gas at such times will be amply provided for by an efficient system of ventilation, and the ignition of the gas avoided by preventing its accumulation and by other precautions and strict regulations enforced by the vigilance of the bosses. Second, a large number of mine explosions, both gas and dust explosions, are plainly due to causes that are independent and have no connection with any special outflow of gas into the workings. Thus, while the importance of daily and hourly observing the barometer in connection with all large mining operations is clearly established, it does not follow that a sudden fall of barometric pressure is signalized by the occurrence of one or more explosions or *vice versa*. It is even claimed by some authorities that periods of high barometric pressure appear from published "colliery warnings" to be the more dangerous for no other reason than because men are less careful at such times than when the barometer is low or falling.

The **temperature** and **hygrometric condition** of the air are so closely associated that the consideration of the one includes that of the other. There has been much confusion of ideas in regard to the supposed influence of each of these conditions in producing an explosion of gas or dust in mines, and much that has been written in this respect will hardly stand the test of a scientific analysis. A full understanding of this important subject involves much that is yet unknown, which fact alone suggests caution. There is the gravest danger in speculation such as that to which reference has already been made, namely, the pernicious practice of reducing the circulation of air in a mine at the time of firing, in order, as it is claimed, to reduce the quantity of available oxygen expecting thereby to reduce the explosive condition of the mine air.

It is pure speculation at present to assert that a saturated condition of the mine air, other things being equal, will reduce its explosive condition to a minimum. This has not been proved, but rather disproved by experiment (Art. 139) and by explosions that have taken place in very wet mines. The attempt to show that the colder seasons of the year are more productive of mine explosions, or that these are attributable to a reduced temperature of the air, has proven almost as futile as the endeavor to show a connection between such explosions and barometric changes, to which reference has been made.

All of these atmospheric influences are operative and each contributes its share towards creating an explosive condition of the mine air, but often in a different way from that supposed. The cold air of winter entering the mine carries with it, at the best, but a comparatively small amount of moisture even if saturated. The temperature of this air being raised by the natural heat of the mine, its capacity for absorbing heat is greatly increased, even exceeding that of ordinarily dry air in summer. The effect of this is twofold—the moisture is taken from the coal dust, which is thus rendered dry and its inflammability increased, and this moisture abstracted from the dust is added to the air, making it better suited to the purposes of combustion.

To overcome the danger due to a cold air-current entering the mine and having its capacity to absorb moisture raised by the natural heat of the mine, it is a good plan to use the exhaust steam of the pumps, if possible, to heat the intake air and saturate the same at a point near the foot of the shaft, so that the air will pass into the workings at a normal temperature and practically saturated. It is common for the air-current in a mine to pick up the moisture of the mine in certain portions of the workings and deposit it at other points, and this process may be repeated several times before the upcast is finally reached. The weight of water in the form of vapor carried up the shaft by the air-current of a large mine, each minute, far exceeds the general expectation. A current of 120,000 cubic feet per minute, returning from the mine in a saturated state at a temperature of 60° F., carries up the shaft 1 ton of water every 20 minutes, or 3 tons per hour. A current of 150,000 cubic feet per minute carries practically 15 gallons, or nearly one-half barrel of water up the shaft per minute under the same conditions. A current of 175,000 cubic feet per minute would deposit, as is often the case (Art. 83), in the fan drift at the top of the shaft, practically one-half gallon per minute for each degree of fall in temperature, or 5 gallons per minute for a drop of

10 degrees from 60° to 50° F., creating thereby a heavy downpour resembling a driving rain.

142. Earth Breathings.—The observations and experiences of mining men are every day making the fact more clear, that subterranean influences are very largely responsible for the spasmodic ebb and flow of gas in the strata, giving rise to irregular periods of frequency of mine explosions. It has been observed for some time that mine explosions occur very often in groups, and that between these periods or groups of explosions there will be irregular periods, during which few explosions will take place. It is not surprising to observe that there is often a seeming contemporaneity, not to say connection, between periods of volcanic activity and the periods of frequency of mine explosions.

In considering a mine explosion there is a general willingness, not to say tendency, to consider the gaseous condition of the workings in any given case as varying only with the physical conditions in the mine, by which is meant those conditions relating to the number of feeders active, extent of faults, area of abandoned workings standing, frequency of roof falls, etc. Sufficient attention has not been given to the variation of pressure of gas that may occur at irregular intervals in the strata. This variation of pressure has its origin within the earth, and results in a more or less spasmodic outflow or emission of gas from the strata, which may be appropriately called *earth breathings*.

The direct result of irregular earth breathings is a corresponding fluctuation in the gaseous condition of all underground workings. This theory, if true, would give rise to **periods of frequency** of mine explosions, assuming that an increased outflow of gas brings an increased ability of explosion. It is clear, however, that explosions *may* occur at times when the outflow of gas from the strata is less, and may *not* occur in the proper periods when the emission of gas is stronger, but these would not necessarily argue against the theory of **periods of danger** in mines. At the most, such errant explosions would only prove that periods of danger in mines are not always periods of frequency of mine explosions. During such periods of danger mine officials and miners should exercise greater care and vigilance, and should employ every precaution to insure safety.

Such a period of frequency would seem to have occurred in 1902, when within less than three months 550 lives were lost in four mine explosions and the terrible eruption of Mt. Pelée occurred, beside a number of other small explosions. It is well to remember that the fatality of the occurrence does not mark its importance in this regard. Few or many may be killed or no fatalities may result, according to the presence of men in the vicinity and the conditions that determine the violence and the extent of the occurrence. The chief occurrences of the 1902-period were the following:

		Lives
May 19,	Frayterville mine explosion, Coal Creek, Tenn.	184
20,	Mt. Pelée eruption, Martinique, West Indies	28,000
23,	Coal Creek mine explosion, Fernie, B. C., Canada	127
July 10,	Rolling Mill mine explosion, Johnstown, Pa.	112
Aug. 1,	Mt. Kembla mine explosion, Wallangong, N. S. W.	127

Then followed a period of quiet, the year 1903 being marked by few explosions; but this period of calm was rudely broken by the terrible disaster in the Harwick mine, at Cheswick, Pa., January 25, 1904, costing 178 lives. The frequency of these occurrences steadily increased. The year 1905 was marked by much unrest, and in the United States alone over 300 lives were sacrificed in thirteen mine explosions (Table 22). The climax was, however, reached in the early part of the following year, and this may rightly be called the 1906–07 period. The chief occurrences of this period, made memorable by their terrible results, are as follows:

		Lives
Jan. 4 to Feb. 19,	five mine explosions, United States.	97
Feb. 21,	Earthquake and tidal wave, Colombia, S. A.	2,000
	Reported activity of Mt. Pelée, Martinique, W. I.	
27,	Cahaba No. 2 mine explosion, Piper, Ala.	9
Mar. 10,	Courrières mine explosion, Pas-de-Calais, France.	1,200
17,	Earthquake, Island of Formosa, Japan; estimated $45,000,000 property loss, and thousands of lives.	
22,	Century mine explosion, Century, W. Va.	21
28,	Takashima mine explosion, Island of Takashima, Kinshu, Japan.	307
Apr. 3,	Mt. Vesuvius eruption began, lasting 14 days; several towns destroyed and hundreds of lives.	
7,	Earthquake, Island of Formosa, Japan, town of Kagi wholly destroyed and 109 lives lost.	

		Lives
Apr. 18,	Earthquake, San Francisco, Cal., $300,000,000 property loss and estimated 2,000 lives.	
20,	Earthquake shocks, Calumet, Mich., and Honolulu; fatal.	
21,	Mine explosion, 40 miles west of Trinidad, Col.	22
	Mt. Hecla, 5,108 feet high, southwest coast of Iceland, reported active.	
	Volcano, 9,000 feet high, north coast Las Palmas, Canary Island, active.	

The late summer of 1906 was marked by continued unrest. The memorable earthquake of August 16, destroying property valued at $250,000,000 in Valparaiso; the severe shocks in Porto Rico, September 27, and the great earthquake recorded as having occurred in the bed of the Indian Ocean, October 1, were followed by mine explosions at Pocahontas, Va., October 3, loss 37 lives; Blossburg, N. Mex., October 5, loss 15 lives; Durham Colliery, Wingate, England, October 15, loss 25 lives; Johnstown, Pa., October 24, loss 7 lives.

From October 6 to 10 Mt. Pelée again threw out clouds of ashes, terminating with a violent eruption on October 11. That this notable period of disturbance has not ended yet is shown by the Kingston, Jamaica, earthquake, first shock January 14; Primero, Col., mine explosion, 20 lives, January 23; Kingston, second shock, January 28, and the same date two mine explosions, Essen, Germany, 275 lives, and Lille, France, 20 lives; the day following, January 29, Stuart mine, Fayetteville, W. Va., 75 lives; and February 4, Thomas mine, Elkins, W. Va., 38 lives.

Such records point strongly to the possible and indeed probable connection between seismic disturbances and periods of danger in mines, if not to periods of frequency of mine explosions, the latter in fact being a possible incident of the former. A study of these facts cannot but be suggestive in respect to the need of exercising greater care at such times in the conduct of all mining operations, and adopting every expedient tending to reduce the explosive condition of a mine. Particular attention should be given to the study of these facts, with respect to their bearing on the working of soft inflammable coals, especially when lying in thin seams, necessitating restricted airways and passageways.

143. Calculation of Initial Pressure of a Gas Explosion.—At the moment of explosion the expansive force of the gaseous products is determined by their relative volume and temperature, referred to the original pressure and volume of the gases exploded. The first step is to determine whether there is any change of volume before and after explosion. In order to do this the equation expressing the reaction that takes place when the explosion occurs must be written. The reaction that takes place in the complete explosion of pure methane or marsh gas (Art. 42) is expressed by the following equation:

$$\begin{array}{lcccccc} & \multicolumn{3}{c}{\text{Before Explosion}} & \multicolumn{3}{c}{\text{After Explosion}} \\ & CH_4 + & 2O_2 + & 8N_2 = & CO_2 + & 2H_2O + & 8N_2 \\ \text{Molecular volumes} & 1 & 2 & 8 & 1 & 2 & 8 \end{array}$$

In this case, which represents the explosion of a body of pure methane in air, there is no change in volume due to the reaction, since the sum of the molecular volumes of the gases is the same after as before the explosion took place. Hence the explosive force must be calculated for the increase of pressure due to the temperature resulting from the reaction, which was found (Art. 69) to be $460+5{,}840=6{,}300°$ F., absolute temperature. Assuming a normal temperature in the mine previous to the explosion, say 60°, or 520° F., absolute temperature; and assuming an original pressure of 14.7 pounds per square inch (sea level), and calling the required pressure x, we have (Art. 62)

$$\frac{x}{14.7}=\frac{6{,}300}{520}, \quad \text{and} \quad x=14.7\times\frac{6{,}300}{520}=178.1 \text{ lb. per sq. in.}$$

In the explosion of carbon monoxide in air there is a change of volume due to the reaction, and seven volumes before the explosion are reduced to six volumes after, which results in a corresponding reduction of pressure. The reaction that takes place, together with the molecular weights, and the relative weights and volumes of the several gases concerned in the reaction and the gaseous products are as follows:

	Before Explosion			After Explosion	
	$2CO$	$+O_2$	$+4N_2$	$=2CO_2$	$+4N_2$
Molecular weights	56	32	112	88	112
Relative weights	1	$\frac{4}{7}$	2	$1\frac{4}{7}$	2
Relative volumes	2	1	4	2	4

The volume being reduced chemically and the gaseous products expanding to the original volume makes the volume ratio affecting the pressure 7:6 instead of 6:7.

To find the temperature due to the explosion the relative weight of each of the gaseous products is multiplied by its specific heat (Table 4), and the sum of the heats thus obtained gives the heat required to raise the temperature of the products of the combustion 1° F. (Art. 69).

Thus, CO_2 $.1539 \times 1\tfrac{4}{7} = .2418$ B.T.U.
N_2 $.1735 \times 2 = .3470$ B.T.U.

Total .5888 B.T.U. required per 1° F. rise.

But these products are obtained from the combustion of one pound of carbon monoxide, which is the relative weight of that gas used in the above equation. Now the total heat produced by burning one pound of carbon monoxide to carbon dioxide is (Table 5) 4,325 B.T.U. Hence the total rise in temperature produced by this reaction is $\frac{4{,}325}{.5888} =$ 7,345° F.; and the resulting temperature is, assuming 60° F. as the original temperature of the gases, $7{,}345 + 60 =$ 7,405° F., or $460 + 7{,}405 = 7{,}865$° F., absolute temperature. Finally, calling the required pressure x, and writing the pressure ratio equal to the inverse volume ratio (Art. 63) multiplied by the absolute temperature ratio (Art. 62), since each of these laws acts independently of the other,

$$\frac{x}{14.7} = \frac{6}{7}\left(\frac{7{,}865}{520}\right);$$

and

$$x = 14.7 \times \frac{6}{7}\left(\frac{7{,}865}{520}\right) = 190.5 \text{ lb. per sq. in.}$$

The effect of the heat developed chemically by the reduction of volume, in this case, and which acts adiabatically to expand the gases, is shown by the use of equation 9 (Art. 48); thus,

$$x = 14.7\left(\frac{\ }{7}\right)^{.83}\left(\frac{7{,}865}{520}\right) = 195.6 \text{ lb. per sq. in.}$$

The chemical heat thus increases the pressure in this case about five pounds.

CHAPTER VI

SAFETY LAMPS

144. Early Practices.—The history of the lighting of mine workings dates back to the early part of the eighteenth century when small candles (tallow dips) were used. These were set or held in a lump of wet clay. When looking for gas the flame of the candle was reduced to a mere glimmer by surrounding the wick below the flame by clay. The candle was then very cautiously raised from the floor toward the roof, the observer screening the brighter portion of the flame with his hand and watching for the first appearance of the pale blue cap above the flame, which was then known to indicate the presence of gas. When this appeared the candle was lowered quietly and its flame extinguished before attempting to drive out the gas. A common and dangerous practice at that time was to get rid of the gas by firing it; this was done by a person selected for his nerve rather than his caution. Dressed in a suit of sackcloth or leather dampened, this man, who was well named a "fireman," would lie prone on the floor of the passage and light the gas above him by raising his candle fastened to the end of a long stick. If he survived, which was not always the case, he would withdraw promptly to fresh air after the flame had passed over him.

Another practice in dealing with gas, and one which until quite recently has been in vogue in some Belgian mines, is that of keeping lamps constantly burning in certain cavities of the roof where the gas would otherwise accumulate. These were the so-called **eternal lamps,** and their purpose was to burn the gas as fast as it came from the strata. The sad results of these and other dangerous practices aroused a deep interest in the subject, and many attempts were made to provide a means of safely lighting underground workings. Various phosphorescent substances, such as the putrefying skins of fish, were carried into the mine, where they were hung up near the working face only to make the darkness visible.

145. The Steel Mill.—About 1750 Carlisle Spedding, a promising young miner of Cumberland, England, not only improved the method of ventilation in mines by *coursing the air*, but invented the "steel mill" for giving light. This mill, as shown in Fig. 17, consisted of a thin disk of steel, so mounted in an iron frame that it could be rotated at a rapid rate by means of a spur-gear and hand-crank. A piece of flint held against the rim of the rapidly moving wheel caused a bright shower of sparks, which gave considerable light as long as it lasted. A boy was employed to turn the mill. Young Spedding had been selected to

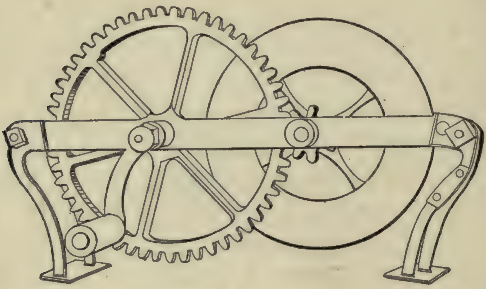

Fig. 17.—The Spedding Steel Mill

take charge of the Whitehaven collieries at Cumberland, and had been sent by the owner of the collieries to New-castle-upon-Tyne to learn more of coal mining. While there he was severely burned by an explosion of firedamp. Five years after the invention of his steel mill, in 1755, he was killed in an explosion of gas at the Whitehaven collieries. The use of both the candle and the steel mill continued—although they were at times the undoubted cause of numerous explosions—till the invention of the safety lamp early in the nineteenth century.

146. The First Mine Safety Lamp.—The honor of constructing the first safety lamp that was ever used in a mine rightly belongs to Dr. William Reid Clanny, F.R.S., Sunderland, England, who described and presented to the Royal Society of Arts his first lamp, May 20, 1813. This lamp was first used, in the slightly modified form shown in Fig. 18, in the Herring Mill Colliery, October 16, 1815, more than two years later. As then used the lamp consisted of a metallic case *a*, made air tight and fitted with a semicircular glass front, as shown. Within the case was a candle, the air necessary for its combustion being admitted or rather forced into the case through a water seal in the bottom by means of the bellows *b* and the tube *c*. The products of the combustion, escaping through the narrow opening at the top of the conical tube or cap *d*, prevented the passage of flame out at that point. The flame of this lamp was

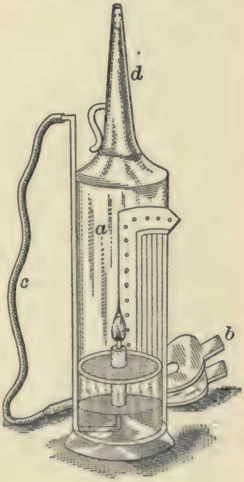

FIG. 18
The First Safety Lamp—Dr. Clanny

therefore completely isolated from the outer atmosphere, but the constant attention necessary to keep the lamp supplied with fresh air prevented its general adoption in the mine. The lamp was much superior as a means of lighting to the steel mill but inferior to either the Stephenson or the Davy lamp, both of which were introduced a few months later.

147. What Constitutes a Safety Lamp.—All safety lamps of the present day consist essentially of an ordinary wick- or gas-fed flame inclosed in a combustion chamber, all the openings to which, for the admission of air or the escape of gases, are carefully protected by wire gauze, or consist themselves of long narrow tubes through which no flame can pass. A safety lamp affords protection only so long as certain conditions regarding its use are fulfilled. These conditions will be described later.

148. The Principle of the Safety Lamp.—The principle on which all safety lamps depend to a greater or less degree is threefold; and as if decreed by fate these three joint principles, each equally important in its relation to the protection and security sought, form respectively the chief characteristics of the original Clanny, Davy, and Stephenson lamps. These lamps may be truly said to have represented in their simplicity the three essential elements in safety-lamp construction as understood today. Dr. Clanny was certainly the pioneer, and demonstrated in his original lamp, May 20, 1813, the first great principle of all safety lamps, namely, providing an inclosed space or *combustion chamber* in which to place the light-giving flame. The means adopted by Dr. Clanny, however, for supplying air to the chamber and preventing the passing out of the flame were wholly impracticable for use in the mine, and it remained for Sir Humphry Davy to discover and proclaim to the world, December 15, 1815, the wonderful property of wire gauze, which under certain conditions would permit the free passage of air through its mesh, while it presented a solid wall to the flame.

Great as was the work so far performed, it would still be incomplete without the additional element of protection that George Stephenson sought to utilize in his first lamps. Mr. Stephenson's theory was "If a lamp could be made to retain some burnt air above the flame and permit the firedamp to come in below in small quantity, to be consumed as it came in, the burnt air would prevent the passing of flame upwards, and the velocity of the current below would prevent its passing downwards." Stephenson's first lamp, tried at the Killingworth Colliery, October 21, 1815, failed to burn satisfactorily; some alterations were made in the lamp and a second trial was made at the same blower, November 9, with slight improvement. The lamp was then reconstructed on different lines and was found on trial, November 28, 1815, at the Killingworth blower, to burn with satisfaction and to be "perfectly safe."

The threefold principle of all safety lamps may then be briefly stated as follows: *Inclosing the lamp flame in a case forming a combustion chamber* (Clanny); *Extinction of flame by the cooling effect of wire gauze* (Davy); *Extinction of flame by confining the burnt air in the upper portion of the lamp* (Stephenson).

149. Safety-lamp Construction.—A few points stated briefly here in reference to the material used and the fitting of the parts and their correlation will be helpful.

The *material* used is mostly brass, aluminum, copper, and iron. Oil vessels are either brass or aluminum; gauzes are iron or copper; the lamp standards are brass or iron;

hoods brass or aluminum, and bonnets sheet iron, brass, or aluminum. Aluminum, while adding a trifle to the cost of a lamp, owing to its not being as workable as brass, possesses certain advantages that have caused it to be used in many lamps. The metal is less than three-tenths the weight of brass, and about one-third the weight of wrought iron, which greatly reduces the weight of a lamp made of this material. It is not as readily corroded by water containing sulphuric acid as is iron or even brass. Although its specific heat (.2143) is higher than that of any other metal used in lamp construction, yet, owing to its lightness, aluminum heats quicker than either brass or iron. Brass is quite generally preferred to aluminum for lamps, chiefly for the reason that it takes a higher polish and is more easily kept clean.

Copper gauzes are sometimes preferred to those made of iron wire, because the copper is more durable and does not burn out or corrode as rapidly as the iron. On the other hand, copper (sp. heat =.0951, sp. gr. 8.9) heats more rapidly than iron (sp. heat =.1138, sp. gr. 7.7), and will therefore pass flame slightly quicker; besides, a copper gauze is not a good gauze for a Davy lamp when testing for gas, because of the strong reflection from the copper wires, which obscures the flame cap.

The *fittings* of a safety lamp must be well made with tight joints. The seams of gauze are lapped, folded, and hammered flat, except in special cases, where they are sewed with wire. Fig. 19 shows in sectional detail the manner of joining the gauze *g* to the base ring *c* by means of the screw collar *r*, which may fit the same thread as the oil vessel *v*. The standards *s* are screwed into the base ring *c*. The wick tube *w* is provided with a flange *f*, by which it is held in place by the screw nipple *n*. The pricker *p* passes up through a small brass tube brazed into the oil vessel. This describes in a general way only the relation of these parts; there are, however, many different forms of construction, in which the several parts are fitted together in various ways. All safety lamps are constructed on the same general principles that formed the chief features of the three lamps previously mentioned. Dr. Clanny's first lamp was of course only useful as demonstrating the first great principle of all such lamps. The Davy and Stephenson lamps were in some respects rival lamps, but it became necessary for Stephenson to appropriate the Davy gauze to improve his lamp and make it more practical for mining use.

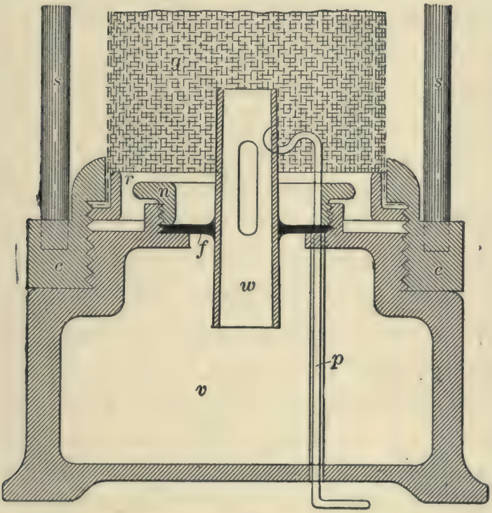

Fig. 19.—Showing Attachment of Gauze to Lamp and General Arrangement of Parts

No one can read the accounts of the controversy that arose, more between the friends of these two rivals than between the men themselves, without feeling impressed with the honest right of each claimant to his due share of the results, which must be considered as jointly operative to some extent in all lamps today. While it is true that Sir Humphry Davy, an educated chemist, undoubtedly approached and solved the problem on a more intelligent basis than did George Stephenson, a practical mechanic, educated in a night school by devoting his spare hours to study, yet the fact remains that as every *lamp gauze* today bears evidence to Davy's scientific skill, so every *bonnet* and *hood* protecting the discharge area of a lamp is a silent reminder of Stephenson's practical insight and ingenuity.

150. Conditions in the Lamp.—When a safety lamp is brought into a gaseous atmosphere the gas entering the lamp mixed with the air burns in the lamp, the products of the combustion passing out through the discharge openings at the top of the lamp. If the feed air is inflammable, it may cause the whole lamp to fill with flame, which condition is called **flaming**. A lamp having a free circulation of air *in* and *out* of the lamp flames more readily, and is said to be more *sensitive to gas* than a lamp in which the free circulation of the air is obstructed by a bonnet, shield, deflector, or other device for controlling the *condition in the lamp*. The upper portion of the lamp is exposed to a greater heat, accumulates more soot and dust, and therefore requires more protection than the lower portion. For this reason the top of the gauze chimney is in most cases provided with a gauze cap, called also the **smoke gauze**, that doubles the security at that point. The gauze chimney in some lamps is covered with a metal bonnet to protect the lamp from strong air-currents. Incidentally the bonnet affords additional security against the passage of flame through the gauze at the top of the lamp, by restricting the circulation and thus confining the burnt air or products of the combustion in the upper portion of the chimney. This burnt air acts as a mantle to extinguish the flame at the top of the chimney. Some lamps have their wick flame more easily extinguished than other lamps, owing to the readiness with which this burnt air descends in the lamp at the slightest cause.

Not infrequently, in a lamp having a good circulation, small balloons of flame will form above the wick flame, when the lamp is exposed to a lively current of sharp gas, as a gas feeder. Slight explosions will then occur in the lamp, and these may be of sufficient violence to drive the flame of the explosion through the gauze. It often happens that the gas entering the lamp is so sharp (unmixed with air) that the wick flame is completely extinguished, while the gas continues to burn in the upper portion of the lamp where it is more diffused. As the lamp is then withdrawn cautiously and fresher air enters the lamp below, the flame may at times dart down from above and relight the wick. So changeful, however, are the conditions producing these phenomena, that they may or may not be repeated in any given trial. The writer has had all of these happen in his lamp within a short time, while examining very gassy workings, and then none of them return again for a long period. The most dangerous condition occurs usually in testing, when withdrawing the lamp from a body of sharp gas. As the lamp is removed from the gas and fresh air enters from below, a very explosive mixture is often formed in the lamp. This is more apt to occur with a closely bonneted lamp than with a lamp having a free circulation.

One peculiar effect, always noticeable within the combustion chamber of a safety lamp, is the diminished activity of the combustion. The flame of the lamp is reduced in size and intensity in proportion to the closeness of the bonnet or chimney and the manner of circulation of air in the lamp. The tendency of an upward current entering below the flame is to lengthen the flame somewhat, while its volume is reduced. In some lamps the effect of the chimney to reduce the activity of the combustion is more marked than in others. At times, when the chimney is first placed over the lamp the flame will diminish and be almost extinguished, as the result of the extinctive gases accumulating in the chimney, but this effect quickly passes off as the circulation starts and the flame recovers itself.

151. Influence of Wire Gauze.—In the flaming of a safety lamp the flame may reach to the top of the gauze chimney and fill the chimney without, however, coming into actual contact with the metal. The absorption of the heat of the burning gas by the cool metal reduces the temperature of the gas in contact with it, below that required for ignition, and the flame next to the metal is extinguished (Art. 121). The passage of flame through wire gauze is rendered more difficult, owing to the passing gas being broken up by the fine mesh of the gauze into numerous tiny streamlets, each of which is surrounded by sufficient metal to abstract enough of its heat to insure the extinction of the flame. The heat thus absorbed is as quickly radiated outwards unless too much gas be present, when a surplus of heat accumulates in the metal and raises its temperature. The heating of the metal is more rapid as the quantity of gas present in the air is greater. The accumulation of heat in the metal soon destroys its power to absorb a sufficient quantity of heat from the passing gas to extinguish the flame, and as a consequence the flame then passes through the gauze and ignites the gas outside of the lamp, causing what is known as a **failure of the lamp.** Flame will thus pass through a lamp gauze when heated to low redness; at this point the temperature of the wire is somewhat above that of the ignition point of pure marsh gas (Art. 140). When fine coal dust is present or other gases, as olefiant gas or hydrogen sulphide, are mixed with the marsh gas the danger point is reached much sooner. A dirty or oily gauze assists the passage of the flame. A slight explosion of gas in the lamp, or a heavy concussion of the air, a sudden fall or jar of the lamp, especially if the gauze is dusty, or exposing the lamp to a strong air-current, may cause the lamp to fail and pass flame.

Mr. James Ashworth proved by experiments (1879) that flame would not pass through the gauze of a Davy lamp when exposed to an air-current containing 4.5 per cent. of pure marsh gas and traveling at a velocity of 370 feet per minute; but the addition of so much fine dust as would be normally carried in suspension in a current traveling at that velocity caused the lamp to pass the flame in 10 seconds. This was due, in the writer's opinion, to the additional heat produced by the combustion of the dust and to the incandescent dust passing out through the gauze. After experimenting with gauzes of different sized wire Davy found that a steel wire gauze containing 28 wires (No. 28 B.W.G.) to the inch, or 784 openings per square inch, gave the best results, and this has ever since continued as the adopted **standard wire gauze** for safety lamps. Davy stated, as the result of his protracted experiments, that "When a cylindrical gauze is used, it should not be more than 2 inches in diameter, for in larger cylinders the combustion of the firedamp renders the top inconveniently hot." He further limited the height of the gauze to 7 inches. The generally adopted standard gauze for Davy lamps is 1½ inches in diameter and 4½ inches high, not including the gauze cap. In the Clanny lamp the height of the gauze is about 4 inches.

152. Testing Safety Lamps.—Any imperfection in a lamp gauze, which may be so small as to easily escape detection by the eye, will at a critical moment cause the lamp to fail. It is therefore necessary that all safety lamps should be tested to ascertain their perfect security before they are allowed to be taken into the mine. The only safe plan is to do this regularly with every lamp after the same is lighted and before it is given out at the lamp house.

It is not likely that a colliery will be provided with an elaborate lamp-testing apparatus as part of its equipment, and therefore it is not generally possible to carry out exhaustive tests as to the velocity of explosive mixture that lamps will withstand, etc. But if the lamps are carefully selected, in the first instance, of a good and approved type, such tests are not necessary. At the same time it is well to have a means of testing the lamps from time to time, more with a view of detecting the defects that may have come into existence with wear and tear, or through carelessness in handling or fitting together. For this purpose a strong wooden box may be used, with a trap door at the top opening upwards, and a door at the side fitted with a window of stout glass to observe the test. Coal gas or feeder gas mixed with air in any proportions desired, can be passed through the box and some means provided at the end of the box for producing a current of any desired velocity. Lamps to be tested are put in singly. A defective lamp will ignite the explosive mixture in the box and the trap door will be blown open by the explosion. There should also be at hand suitable means for the daily testing of all safety lamps taken into the mine.

CLASSIFICATION OF SAFETY LAMPS

153. Classification.—All safety lamps may be divided into two general classes, according to the use for which they are designed:

(*a*) Lamps for testing for gas;

(*b*) Lamps for general use.

From the nature of the conditions a good lamp for testing does not make a good lamp for general work. The test for gas by means of a safety lamp requires that the lamp be sensitive to gas; the gas must have ready access to the flame, and the condition within the lamp must represent correctly the condition of the air outside of the lamp. In order that this may be the case, the lamp must be so constructed as to permit of a good circulation of air *in* and *out* of the lamp. On the other hand, a good lamp for general work must be less susceptible to the presence of gas; the chief purpose of this lamp is to give light and protection. Thus it is clear that the conditions and requirements of these two classes of lamps are essentially different.

154. Lamps for Testing for Gas.—The *principal requirement* of a lamp designed to be used exclusively for testing for gas, as explained above, is, such a circulation of air through the lamp as will insure the same gaseous condition of the air surrounding the flame within the lamp as that of the air outside of the lamp. This is necessary in order that the indications of the flame as observed within the lamp shall correctly represent the state of the mine air with respect to gas; it is the first requirement of a testing lamp, and practically determines its sensitiveness. This freedom of circulation is best secured by arranging for the free admission of the air and gas, either through the lower portion of the gauze chimney at a point not above the flame, as in the Davy lamp (Art. 157), or through openings in the lamp itself at a point below the flame, which may be called the **Eloin principle** (Art. 155) though adopted also in other early lamps.

The *second requirement* of a testing lamp relates to the protection that its construction must afford, *first*, against strong air-currents or a concussion of the air; *second*, against the transmission of flame at the top of the lamp, which is the danger point for all lamps. The danger of the transmission of flame through any portion of the gauze chimney is always greater in a testing lamp, because its continued and repeated exposure to bodies of gas often renders the lamp very hot, so that, in the writer's experience, it could not be held comfortably in the hand. Protection against air-currents and concussion of the air is best secured by a shield, which should be movable, so that it can be slid up and down outside of the gauze, as the condition of the mine may require, as in the Hughes Evan Thomas lamp (Art. 157). Protection against transmission of flame is best secured by the use of a double gauze chimney, which, as will be seen later, is the characteristic feature of the Marsaut lamp (Art. 162).

The *third requirement* of a testing lamp relates to the accurate measurement of the height of the flame cap produced by the gas present in the air. The height of this flame cap increases with the percentage of gas present, and thus furnishes a means of determining that percentage more or less closely, according to the accuracy of the measurement of the height of the cap. It has been the custom for a long time to guess at the percentage of gas, or rather guess at the relative gaseous condition of the mine air from the appearance of the cap. This flame cap, however, cannot be discerned by the ordinary observer when less than 2 per cent. of gas is present in the air; others cannot detect the cap with certainty under 2.5 per cent., and many fire bosses report "no gas" for anything under 3 per cent., being unable to see the faint, non-luminous cap formed above the flame by the gas till a dangerous proportion of gas is present in the air. This method clearly depends wholly on the observer's ability to discern the cap, and to correctly measure its height with his eye, making possible a twofold error at any time. In a recent discussion of this subject that took place in a meeting of the Institution of Mining Engineers, England,* it was stated that the observance of a small flame cap by two individuals will differ according to the object each has in view. An instance was cited where a mine inspector and a mine overman, both experienced mining men, entered a place where the inspector wanted to show the presence of gas; the overman failed to detect the flame cap, which was plainly visible to the inspector. Shortly after, the inspector failed to see any appearance of gas on the flame in the overman's lamp in another heading where the latter claimed he had found gas. As a matter of fact, there is too much guessing in the method of detecting the presence of gas by the height of the flame

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* Transactions of the Institution of Mining Engineers, Vol. xxvi., p. 217.

cap, which is very indistinct except when the proportion of gas reaches 3 per cent.

An important requirement of a good testing lamp is therefore some simple means of gauging the height of the flame cap and, if possible, indicating the presence of small percentages of gas. Any device for this purpose must be simple, inexpensive, and adapted to a small lamp of light weight, such as a fire boss would use in making his rounds. These requirements are met in the simple Beard-Mackie Sight Indicator (Art. 204). Some special testing lamps have been devised to burn alcohol, naphtha-benzine, or hydrogen, so as to render the flame more sensitive to small percentages of gas. Such are the Pieler, the Stokes, and the Ashworth lamps burning alcohol; the Wolf lamp burning naphtha-benzine, and the Clowes hydrogen lamp. The flames of all of these lamps, however, are easily extinguished and require extra care in making the test for this reason. They are besides, for the most part, expensive, heavy, and inconvenient.

155. Lamps for General Use.—The *first requirement* of a safety lamp for general use is maximum illuminating power consistent with conditions of safety. This should not depend on the burning of a highly volatile oil. Such an oil, even when absorbed in cotton, is a menace to safety, either from a possible leak or from the explosive vapor that fills the combustion chamber of the lamp, after the lamp has been extinguished for a short time, and which causes the lamp to flash when it is relighted. Good illumination should be secured by improving the circulation in the lamp, and by so arranging the admission of air to the flame that the circulation in the lamp will always be ascensional. By this means there will be no conflicting air-currents within the lamp, and the common tendency of the lamp to smoke will be largely avoided. The majority of the working lamps in common use admit the air at a point above the flame, and to reach the flame this air must pass downwards in the lamp. A few lamps are designed on what may be called the **Eloin principle;** these lamps admit the air through gauze-protected openings at a point below the flame. By this method a direct upward draft is produced, the circulation in the lamp is wholly ascensional, and the illuminating power of the lamp is greatly improved.

In Fig. 20 the arrows show the manner in which the air enters the lamp through the openings *o* in the lower ring *c* of the chimney, and passes upwards through openings in the plate *a* into the *combustion chamber m*. The ring *c* is provided with two threads of slightly different diameter, the one above the openings *o* for holding the plate *a*, which supports the glass chimney *b*, and the other below the openings for holding the oil vessel *v*. The standards *s*, which support the upper plate forming the base of the gauze chimney above the glass, are firmly riveted into the base of the ring *c*. Flat washer rings of asbestos are fitted underneath and above the glass chimney *b*, so as to make a tight joint. The openings *o* are protected by a gauze ring that fits snugly inside the ring *c*. The wick tube *w* is supported by a thin brass disk fastened to it near its lower end. This disk fits within a collar turned on the upper surface of

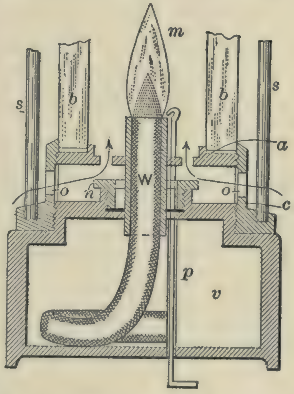


FIG. 20.—Showing Principle of Eloin Safety Lamp admitting Air below the Flame

the oil vessel, and is held in place by the nipple *n*, which screws into the collar. The small rod *p* running up through a fine tube brazed into the oil vessel is the *pricker* for raising and lowering the wick to regulate the flame.

Good illumination requires that the lamp flame be set sufficiently high in the combustion chamber not to cast too wide a shadow on the floor.

The *second requirement* of a good working lamp is security against strong air-currents. The most common form of protecting the lamp in this respect is to incase the gauze chimney in an iron or steel bonnet provided with suitable openings at the top of the bonnet for the escape of the products of combustion from the lamp. The bonnet incidentally restricts the outflow or discharge from the lamp, and thus affords an additional protection against the transmission of flame at the top of the lamp. Instead of the bonnet, or sometimes in addition to the bonnet, double gauzes or triple gauzes are used, as in the Marsaut lamp. A good protection against explosion of gas in the lamp is the sheet-iron, conical chimney of the Mueseler lamp (Art. 167); but this lamp is easily extinguished by canting to one side, owing to the change that then takes place in the circulation in the upper portion of the lamp, which drives the burnt air and gases downwards upon the flame. The bonneted Marsaut lamp when properly constructed will give as great protection as any means thus far employed.

The *third requirement* relates to simplicity of construction, an important element being the fewness of parts. The parts of a safety lamp should, as far as practicable, so depend one on another that the lamp cannot be put together without all its parts being in place. It should be practically impossible to put a bonneted lamp together and omit the gauze; but with certain lamps this has been done inadvertently. To avoid accident arising from such oversights and from any slight defect in the gauzes or glass, it should be customary to regularly test every lamp in a box, through which is made to pass a current of feeder gas diluted to its most explosive point. It is not sufficient, as has been done in some instances, to expose the lamp while burning to a jet or blower of gas to see whether the gas would be ignited. The issuing gas is diffused so rapidly into the air that the chances of ignition taking place through any possible defect in the lamp coverings are very slight. In one instance a lamp having a hole the size of a slate pencil punched purposely in the top of the gauze failed to ignite a piped jet of feeder gas to which it was exposed for some time. The lamp must be surrounded by an atmosphere of gas at the explosive point in an inclosed space, in order to detect any possible defect in the lamp.

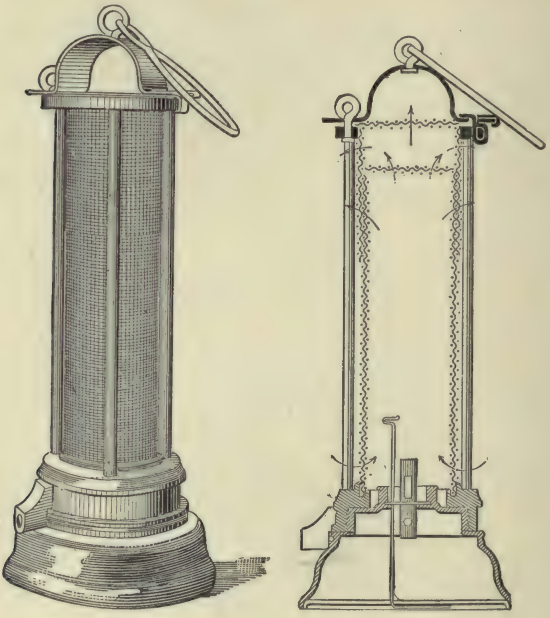
A *fourth requirement* is that a lamp for general use in the mine should be provided with a lock fastening that will plainly reveal any attempt to open the lamp. Of the different forms of locks that have been employed the lead-plug lock (Art. 178) seems to give the best satisfaction, because of its simplicity and the security it affords, which is as great as that of any other lock.

TYPES OF SAFETY LAMPS

156. In the following description of the different types of safety lamps no attempt will be made to separate lamps that are specially adapted to the work of testing for gas from those adapted to general work, since some are adapted and designed to meet the requirements for both purposes.

The description of each lamp will have particular reference to its distinctive features, and only those lamps will be described that possess such features, or have come into general use.

157. The Davy Lamp.—This lamp consists of an oil vessel of brass or aluminum surmounted by a cylinder of wire gauze to which it is attached by a screw joint. Fig. 21 shows an unbonneted Davy and a sectional elevation of the same, the arrows indicating the circulation of the air *in* and *out* of the lamp. The wire gauze forming the chimney in the standard Davy lamp is $1\frac{9}{16}$ inches in diameter and varies from $4\frac{1}{2}$ to 6 inches in height, the



View

Section

Fig. 21.—Unbonneted Davy Lamp

former being used in what is called the *fire-boss Davy* (Fig. 22). A still smaller sized lamp called the *pocket Davy* has a gauze 4 inches high. In each case the gauze is surmounted by a gauze cap to afford greater protection at the top of the chimney. As shown in the figure, the lamp has three *standards* or upright rods that serve to unite the upper and lower rings supporting the gauze. The bale or handle of the lamp is attached to the hood that protects the top of the chimney from falling dust and dirt or water.

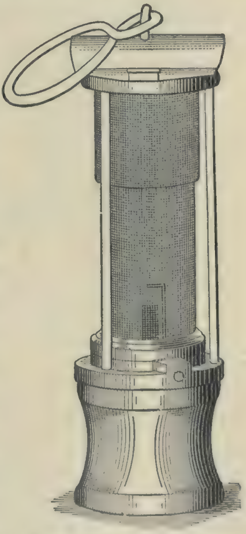
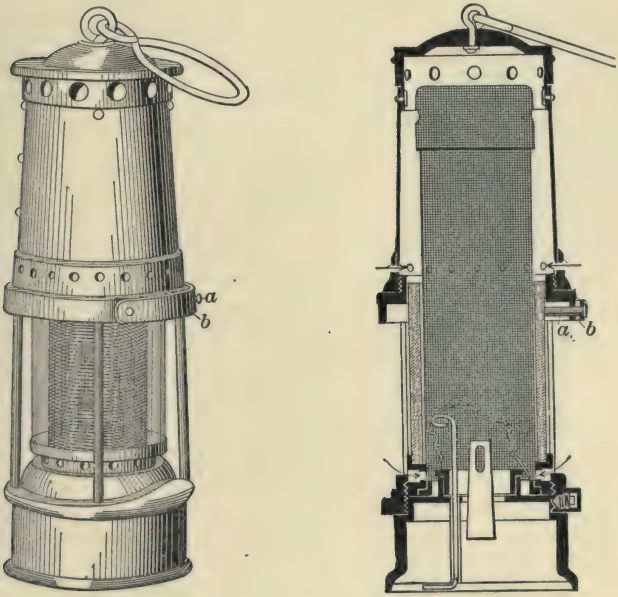


FIG. 22.—Fire-boss Davy Lamp

The distinctive feature of the Davy lamp is its large gauze area, admitting of a free circulation of air *in* and *out* of the lamp, and making this lamp extremely sensitive to gas. The condition within the lamp represents correctly the gaseous condition of the outer air, and for this reason the unbonneted Davy makes the best form of testing lamp. Owing to its sensitiveness the lamp *flames* readily, and is therefore a dangerous lamp to place in the hands of the ordinary miner, or to use at the working face for any purpose other than testing. The unbonneted Davy lamp is unsafe in an explosive current, having a velocity exceeding 6 feet per second, or 360 feet per minute. The different forms of protected Davy lamps are able to withstand current velocities varying from 600 to 1,200 feet per minute. The *tin-can Davy* has successfully withstood a velocity of 2,000 feet per minute without causing an explosion. The illuminating power of the Davy lamp will not average above .16 candle power. The use of the Davy lamp in the mine, except for the purpose of testing for gas, is prohibited by the bituminous mining laws of Pennsylvania; the mining laws of England permit of the use of the bonneted Davy only, for testing for gas; and in France and Belgium the Davy is wholly excluded from the mine. The Davy lamp is constructed to burn sperm or lard oil or colza. Numerous types of the Davy lamp have used different forms of oil vessels; that known as the Newcastle had a wide expanding base (Fig. 21); another type has a straight oil vessel (Fig. 20); while the American fire-boss Davy has usually an oil vessel shaped like a dice box (Fig. 22).

In England, various forms of cases have been used for shielding the Davy. One of these, an early form called the **Davy in case,** or the **tin-can Davy,** consisted of a metal shield covering the entire lamp and provided with a glass window in one side, which gave the lamp the appearance of a lantern. Another form was similar to the first, except that the window was replaced by a glass cylinder that encircled the lamp, giving it the appearance of a bonneted Clanny lamp. Still another form consisted of the ordinary Davy, but having a glass cylinder surrounding the gauze chimney for its full height; it was called the *Davy with glass shield.* The *Davy Jack* or *Jack Davy,* sometimes called the *fire tryer's* or *gas finder's* or *fireman's* lamp, was a Davy of smaller size corresponding to the American fire-boss Davy and the pocket Davy. These small sizes of Davy lamps heat quickly and are not safe in presence of much gas. Fire bosses often prefer them for their small size, which allows of the lamp being carried in the pocket, or held in the teeth when climbing over falls.

A *Davy lamp with bonnet and glass shield,* that has given good satisfaction both here and in England, is shown in Fig. 23. This lamp was designed by Mr. W. S. Hughes, Scranton, Pa., who was at the time he designed the lamp associated with Mr. Evan Thomas, England; the lamp has thus come to be known as one of the many Evan Thomas lamps. The lamp consists of a common Davy provided with a special wide brass ring at the base of the gauze chimney. This ring has openings for the admission of air on the *Eloin principle,* as shown by the small arrows, and is joined by standards to another ring at the base of the bonnet. The lower ring screws onto the top of the oil vessel in the usual manner, while the upper ring is threaded



View Section

Fig. 23.—Hughes-Evan Thomas Lamp

to receive the bonnet. Holes for the admission of air, as shown by arrows, are made in the lower portion of the bonnet, while at the top somewhat larger holes are provided for the escape of the products of combustion.

The interesting and useful feature of the lamp is the sliding glass chimney that rests on the lower ring and extends to just above the upper ring, thus surrounding the lower half of the gauze, below the metal bonnet, and affording the much-needed protection of the flame from strong air-currents. When desired in testing for gas in chambers or rooms where the air has a more moderate velocity, the glass cylinder can be raised so as to occupy the space between the bonnet and the gauze, and is held in this position by the small pin *a* operated by the spring *b*. This leaves the air free to enter the lamp through the lower portion of the gauze, and makes an excellent testing lamp when properly used.

FIG. 24.—The Scotch Davy Lamp

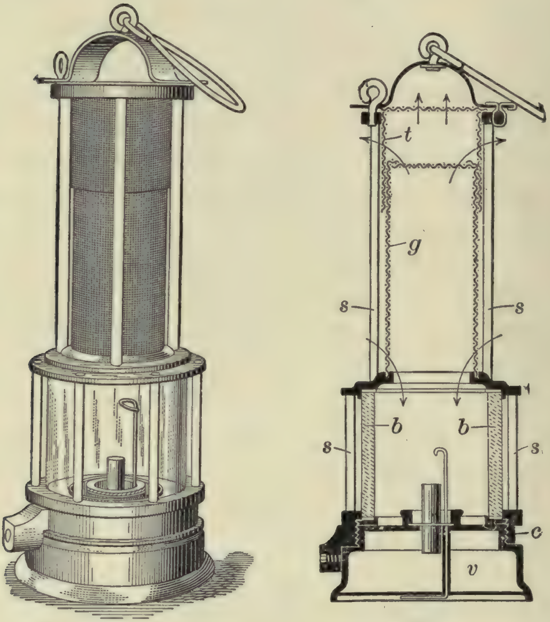
The **Scotch Davy** (Fig. 24) was for a long time a favorite lamp in the mines of Scotland. The lamp has an extremely home-made appearance, but its particular point of interest is the fact that it was constructed contrary to the results obtained by Davy in his experiments (Art. 151). The diameter of the gauze of the Scotch Davy was 2.9 inches and its height 10 inches to the base of the conical cap. This height was afterwards reduced to 7 inches, but the actual length of gauze exposed was only 4½ inches, owing to a rim of sheet copper 2 inches wide at the bottom of the chimney, and another metal band ½ inch wide at the top. The gauze was fastened by heavy rivets, and a double thickness of gauze was used at the top of the cap. This covering set tightly into a cup of sheet copper, holding a socket or pedestal 1½ inches in height, which could be used either to support a tallow candle or an oil lamp. The lamp used was a small tin oil vessel having a flat burner; to the side of this vessel was attached a tin shield shaped like a round-pointed spade to protect the flame of the lamp from a strong draft. Accidents that were traceable to the use of this lamp in the mine, finally (1886) led to the appointment of a committee to investigate the subject and recommend a proper lamp as a substitute for the one in use. So strong was the prejudice, however, in favor of the lamp, that a number of colliery officials were found who were strongly opposed to giving up the old lamp. The incident serves to illustrate the strong prejudice that exists generally among practical mining men that leads them to oppose the adoption in the mine of something that is unfamiliar and untried. This prejudice is not scientific, but is born of environment.

158. The Stephenson or "Geordie" Lamp. — There is no accurate description of the original Stephenson lamp at hand. This lamp was ordered made from Stephenson's drawings, October 2, 1815, and tried in a gas blower at Killingworth Colliery, October 21, without satisfactory results. The lamp admitted its air through a half-inch tube in the bottom of the lamp, the tube being provided with a sliding tip to reduce the size of the opening. Some alterations were then made and the lamp again tried in the same blower, November 9, with but slight if any improvement in the burning qualities of the lamp. The theory on which Mr. Stephenson operated was that by confining to a certain extent the products of the combustion in the upper part of the lamp, and restricting the inflow of air and gas below, the flame of any gas burning in the lamp would be prevented from passing upwards and out of the lamp by the extinctive gases in the top.

The present Stephenson, or "Geordie" lamp as it is commonly called, resembles in its outward appearance the Davy lamp. The gauze chimney is 2.1 inches in diameter and 6½ inches high, and has no gauze cap above or *smoke gauze,* as this cap is frequently called. The gauze chimney incloses a very slightly conical glass chimney 1.9 inches in diameter and 5 inches high. This glass chimney is surmounted with a perforated copper cap that takes the place of the smoke gauze. The glass chimney is loose within the gauze, and in most of these lamps can be raised slightly, so as to admit air more freely at the bottom. The lamp is arranged to burn ordinary sperm or lard oil. It is a great favorite with some fire bosses and is still used in certain localities in Pennsylvania for the purpose of testing. It is claimed by those who use the lamp that it is superior to the common Davy for this work. The glass, however, produces a reflection that interferes with the careful observance of the flame cap. Its illuminating power is less than the Davy, being about .10 candle power.

159. The Clanny Lamp.—The improved Clanny lamp is the most common form of safety lamp for general work and the most widely used, owing to its simplicity. It is an essentially different lamp from that first designed by Dr. Clanny (Art. 146). In his improved lamp Dr. Clanny adopted the wire-gauze chimney of the Davy lamp, replacing therewith the conical cap of his first lamp; he also substituted for the glass window of his first lamp a cylinder of glass. There was now no further need of the bellows attachment for forcing air into the lamp, as the circulation was natural. The improved lamp was in fact a Davy lamp, in which the lower portion of the gauze was replaced by a glass cylinder $2\frac{1}{4}$ inches in diameter and the same height, leaving practically a 4-inch gauze above the glass. This greatly improved the illuminating power of the lamp, making it in this respect much superior to the Davy; it also gave added protection to the flame, adapting the lamp better to the purposes of general work, as this lamp was less sensitive to gas.

Fig. 25 shows a view and sectional elevation of an unbonneted Clanny lamp. As indicated by the arrows, the air enters the lamp through the lower portion of the gauze and must descend to reach the flame, while the products of combustion rising in the center of the lamp pass out through the top of the gauze. These two conflicting currents create in the lamp a tendency to smoke, which dims the glass and reduces the illumination. The lamp is provided with a gauze cap to give greater protection at the top of the chimney where the heat and pressure of the ascending currents are greatest. An ordinary pricker for raising and lowering the wick passes up through the oil vessel as shown. The lamp is usually constructed to burn ordinary sperm or lard oil, except when, for a special purpose, another illuminant is desired; the oil vessel must then be adapted to the purpose. A flat burner is frequently used in this lamp instead of the round burner shown in the figure. The lamp is used with or without a bonnet, according to the conditions in the mine where it is used. The unbonneted Clanny is unsafe in an explosive current having a velocity exceeding 8 feet per second or 480 feet per minute. The letters in Fig. 25 correspond to those used in Figs. 19 and 20 and already explained in Arts. 149 and 155.



View

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Fig. 25.—Improved Unbonneted Clanny Lamp

The various types of bonneted Clanny lamps afford security varying with the construction of the lamp, and are able to withstand current velocities varying from 1,500 to 2,000 feet per minute. Some makes of this lamp have been provided with tangential openings in the bonnet for deflecting the air as it enters the lamp, which feature has increased its security. The illuminating power of the different types of Clanny lamps varies from .25 to .50 candle power, depending on the form of construction. The use of the unbonneted lamp is prohibited by the bituminous mining laws of Pennsylvania; the lamp is practically debarred from the mines of Great Britain, and is wholly excluded from the mines of France and Belgium.

160. The Evan Thomas No. 7.—There are a large number of lamps known under the general name of the Evan Thomas lamp. For the most part these are all some modification of the bonneted Clanny lamp. One of these, known as the Evan Thomas No. 7, has been found to give a much greater amount of security than other forms of bonneted lamps with single gauze chimneys. The characteristic feature of the lamp is the special manner of protecting the intake and the discharge openings, so as to maintain an atmosphere within the lamp wholly undisturbed by the movement of the air outside. The letters in this figure are the same as those used to indicate the corresponding parts in Figs. 19 and 20. As indicated by the arrows, the air enters the lamp through the openings *o* in the lower end of the bonnet; here it strikes the brass deflector ring *d* that encircles the lower portion of the gauze *g*. The deflector is secured to the gauze by the screw

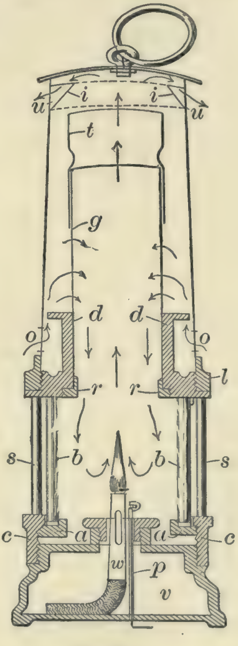

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Fig. 26.—Evan Thomas No. 7

collar *r*; at its top is a broad flange that almost closes the space between the gauze and the bonnet. Through this annular opening $\frac{1}{16}$ inch wide the air entering the lamp must pass before it reaches the gauze, where it enters the combustion chamber *m* above the flame. The openings *u* at the top of the bonnet, for the discharge of the products of combustion, are protected within by a conical deflector *i*, over which the heated gases must pass, through a narrow slit between the deflector and the top of the bonnet. The gauze *g* is surmounted by a smoke gauze or cap *t*, which fits tightly over the main gauze, and is generally indented as shown, to prevent its slipping down too far and blocking the gauze below where the air must enter the lamp.

In this lamp is realized the principle of the Stephenson lamp, since the flame is extinguished just above the lower edge of the smoke gauze where it loses the oxygen of the entering air. On this account but a small area of the gauze is heated by proximity to the flame, which fact greatly increases the security of the lamp. This lamp has been tested and did not fail, in an explosive current having a velocity of 3,200 feet per minute. The flame continues to burn steadily, even when the lamp is considerably inclined from the vertical, and is extinguished only when a horizontal position has almost been reached. Swinging the lamp, or rapid upward or downward motion does not seriously affect the flame. The lamp has an illumination of .40 candle power. Like all Clanny lamps of this type it has a tendency to smoke, owing to the conflicting currents, as shown by the arrows. The bonnet is arranged to screw on the base of the deflector ring, to which also the standards *s* are attached. The same ring also forms the upper seat for the glass chimney *b*.

One of the standards is made movable and lengthened, so as to pass through the base ring *c*, and by this means the bonnet is locked when the oil vessel is screwed in place, by the standard being forced upwards into a hole in the ring *l*, which forms the bottom of the bonnet.

What is now known as the **Cambrian lamp** is a modification of the No. 7 lamp shown in Fig. 26. In the Cambrian lamp the deflector or cylindrical baffler has been removed, because it checked the current or circulation in the lamp and reduced its illuminating power. This lamp has also been fitted with an automatic air lock, which locks as the oil vessel is screwed into place, but which requires a powerful air pump to unlock the same (Art. 178).

Another form of Evan Thomas lamp is a bonneted Clanny similar to that shown in Fig. 26, except that the lamp has two glass cylinders, one within the other, with a thin annular air space $\frac{3}{16}$ inch wide between them. There is no deflector *d* to deflect the entering air upwards, but the air passes down between the two glass cylinders and enters the combustion chamber at a point below the flame. This arrangement not only keeps the glasses cool and perhaps improves their power to transmit light, but avoids the tendency of the flame to smoke by creating a direct circulation upwards through the combustion chamber and thus greatly improves the illuminating power of the lamp.

161. The Bull's Eye (Mauchline) Lamp.—This lamp, Fig. 27, does not differ in principle from an ordinary Clanny lamp. The lower portion of the lamp casing, however, consists of a brass cylinder *a*, having a strong convex lens *b*, about 2 inches in diameter inserted in and forming the front of the lamp; two small round openings *c*, one on each side of this casing and protected by wire gauze afford opportunity to observe the flame. A reflector *d*, at the back of the lamp, behind the flame, concentrates the light rays on the lens. As shown in the figure, the metal casing is surmounted by a gauze chimney *g* and cap *t*, similar to the ordinary Clanny lamp. The air enters the lamp by the gauze openings *c*, at the side, as well as through the lower portion of the gauze chimney. The lamp is generally used without a bonnet; it throws a strong light in one direction only, and was designed by Mr. Mauchline as a surveyor's lamp.

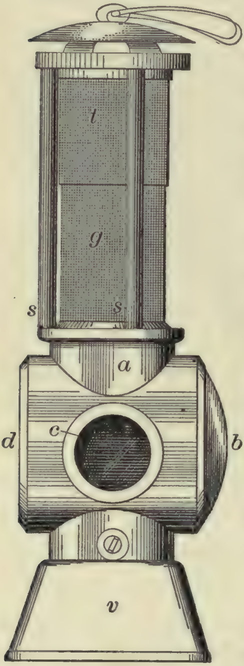

Fig. 27. — Mauchline's Bull's Eye Clanny Lamp

162. The Marsaut Lamp.—The bonneted Marsaut (Fig. 28) is to all outward appearance a bonneted Clanny, but the sectional view on the right shows that the inner construction differs from that of the Clanny by having more than one gauze forming the chimney. The lamp shown in the figure has three gauzes; other Marsaut lamps have but two gauzes. The multiple gauze is the characteristic feature of this lamp. In all other respects the lamp is identical with the Clanny lamp. The lamp may be used with a bonnet as shown here, or where the conditions are such as not to require the protection afforded by the bonnet this is omitted. The unbonneted Marsaut is much safer for common use than an unbonneted Clanny lamp, although no unbonneted lamp should be used under conditions where the gauze will be exposed to much dust and dirt. An unbonneted lamp in constant use should have its gauzes carefully cleaned at the end of each shift.

The multiple gauzes of the Marsaut lamp are a great protection to the upper portion of the lamp, as the space between the gauzes becomes filled with extinctive gases, especially where the lamp is bonneted or the intake openings are at all restricted. The multiple gauze chimney has been found by the writer to be extremely valuable for the protection of lamps that admit the air below the flame, and thus have a strong draft naturally. On this account

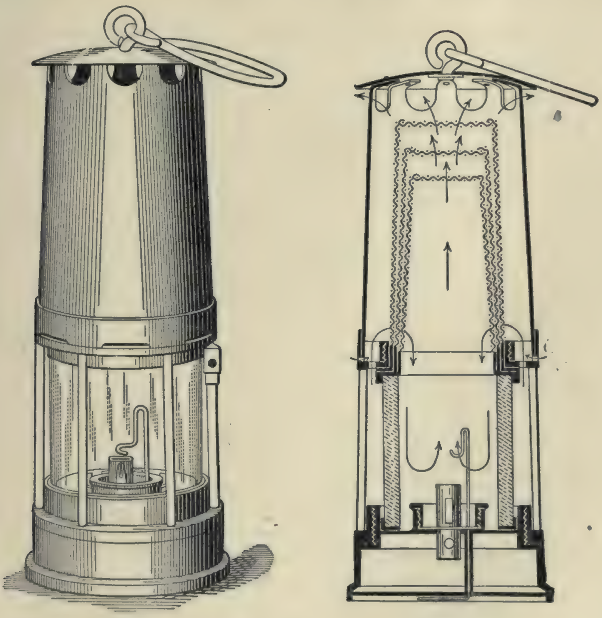

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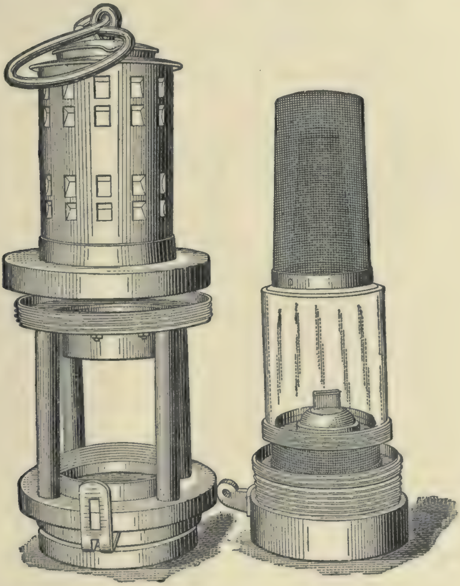
FIG. 28.—Bonneted Marsaut Lamp—Three Gauzes

any lamp built on the Eloin principle of admitting the air below the flame should combine with this the principle of the multiple gauzes of the Marsaut lamp. The two-gauze Marsaut has been found to be safe in an explosive current having a velocity not exceeding 2,600 feet per minute, while the three-gauze lamp has easily withstood a velocity of 3,100 feet per minute, without showing any signs of failing, after an exposure of two minutes, the inner gauze being then a bright red and the second gauze a dull red, while the outer gauze remained dark and cool. The illuminating power of the two-gauze lamp is .70 candle power when first lighted, reducing to .60 after burning a half-hour; while that of the three-gauze lamp is about .50 candle power, reducing after a half-hour to .45. Like the Clanny this lamp has been commonly designed to burn ordinary sperm or lard oil, but at times, for special purposes, the oil vessel has been adapted to burn a more volatile oil.

163. The Gray Lamp.—Primarily the Gray lamp consists of a bonneted Marsaut having two gauzes but admitting the air below the flame on the Eloin principle. The distinctive feature of the lamp consists of the large hollow tubes, which serve the double purpose of standards and of conducting the air into the lamp from a point nearer the top of the lamp. Fig. 29 shows the Gray No. 2 lamp, in which the tubes extended only to the base of the bonnet; the lamp is shown here in sections so as to make clear its construction. The tubes forming the standards of the lamp are called the *Gray inlet tubes.* Later a single tube was added, extending one of the standard tubes to the top of the bonnet, which enabled the lamp to draw its air from above and thus to test a thin layer of air at the roof for which purpose the lamp was designed. The glass of this lamp was a cylinder, as was also the outer gauze, while the inner gauze was conical as shown. The bonnet is made to screw onto the upper plate above the standards. The openings in the bonnet are punched in such a way as to deflect the entering air and break the force of a strong air-current or concussion of air. This is the Ashworth bonnet. As appears in the figure, the openings are arranged in two sets, the lower being the intake and the upper the discharge openings. On the inside of the bonnet is a shield dividing the two and deflecting the intake air downwards to the tubes, which lead to the combustion chamber entering this below the flame.



Bonnet Removed Lamp and Chimney

FIG. 29.—Gray No. 2 Lamp

The Gray lamp is made to burn sperm or lard oil; its illuminating power is .38 candle power when first lighted, but reduces in a short time to .33 candle power. The flame of the lamp is not much affected by inclining the lamp, or by swinging, or by rapid motion up and down. The lamp has been tested without causing an explosion in an explosive current having a velocity of 3,000 feet per minute; the glass, however, was cracked by the heat, but the lamp did not fail during an exposure of 1 min., 40 sec.

An annoying feature of the Gray lamp was that when the lamp was introduced into a body of sharp gas, the gas entering the lamp would extinguish the flame before the lamp could be withdrawn and pure air could reach the combustion chamber. This was largely or wholly due to the fact that no pure air could reach the flame till all the gas filling the inlet tubes had passed into the lamp, which was sure to extinguish the light. This and other considerations led later to the construction of a lamp combining the best features of the Gray and the Ashworth lamps.

164. The Ashworth Lamp.—This was primarily a testing lamp though used also for general work. The distinctive features of the lamp (Fig. 30) were a double bonnet, the outer one *a* being perforated in different ways and having a greater or less number of holes *o* for the admission of air to the annular space between the two bonnets, and the inner one *t* having holes *p* at the bottom through which the entering air reached the combustion chamber *m*, and being surmounted by a truncated cone *i* that reached almost to the discharge openings *u* in the top of the bonnet. The conical glass chimney *b* was surmounted by a small conical gauze *g*. In this lamp the usual pricker was replaced by an arbor carrying two toothed wheels for moving the wick up or down when alcohol was used. Three forms of oil vessels *v* were used in this lamp, designed to burn paraffin spirit, or oil,

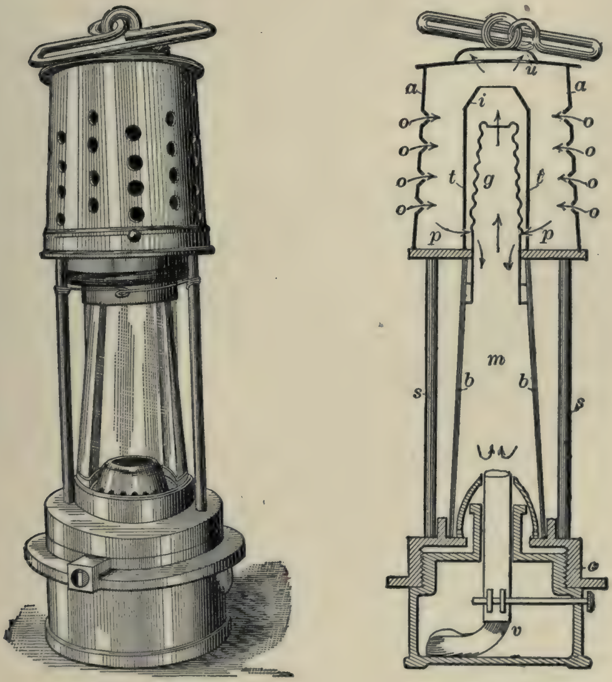


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Fig. 30.—The Ashworth Testing Lamp

respectively. These oil vessels are shown in Fig. 31. The illuminating power of Ashworth No. 4 lamp was .68 after being lighted a few minutes, but this reduced to .55 after burning half an hour.

The particular Ashworth features in these lamps are the conical glass and the double bonnet, the inner bonnet *t* being surmounted by a truncated cone *i*. Conical gauzes had been used in earlier lamps. The lamp, though possessing admirable features, was prone to go out when inclined to a considerable angle from the vertical, owing to a change being produced in the circulation, which brought the burnt air and gases from the top of the lamp down on the flame. There were other forms of Ashworth lamps that differed from each other in unimportant details. The Ashworth tester, burning oil and alcohol (Fig. 42) will be described later.

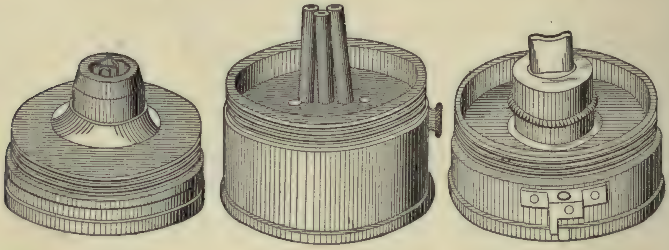
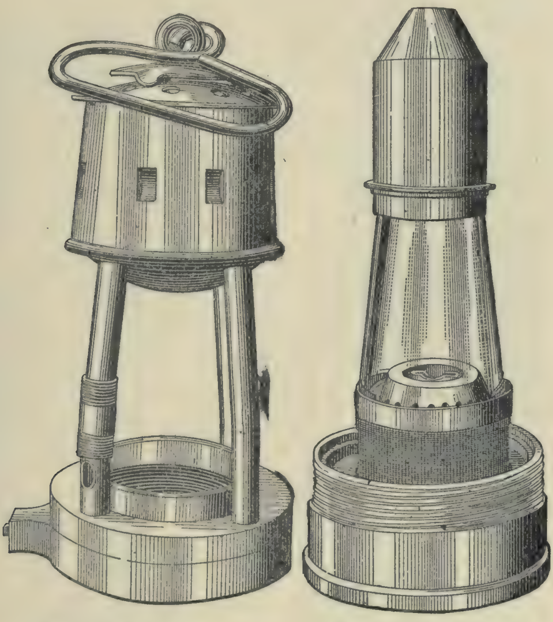


FIG. 31.—Vessels of the Ashworth No. 4 Lamp

165. **The Ashworth-Hepplewhite-Gray Lamp.**—This lamp combines the best features of the Gray and Ashworth lamps described above. The short pattern A-H-G lamp is shown in sections, in Fig. 32, which makes clear its essential features. On the left of the figure is shown the oil vessel and resting on this a gauze ring, through which the air brought down the inlet tubes or standards enters the combustion chamber. Above the gauze ring is a plate that forms the seat for the conical glass chimney surmounted by the inner bonnet of the Ashworth lamp.

This inner bonnet, as shown, is a cylinder topped with a truncated cone. Within the inner bonnet is the small conical gauze. In this lamp, unlike the Ashworth lamp, the intake air does not enter through the gauze chimney, but passes down the standards and finds admission below the flame. The entire gauze area above is therefore available for discharge, which makes possible a smaller gauze. The space between the inner bonnet and the gauze chimney is, moreover, a great source of protection, because the gauze is completely surrounded, in fact immersed, in an extinctive atmosphere of burnt air and gases



Bonnet Removed Lamp and Chimney

FIG. 32.—Ashworth-Hepplewhite-Gray Lamp—Short Pattern

that prevents the flame of any gas burning in the lamp from approaching the gauze. This extinctive zone at the top of the lamp illustrates the Stephenson principle, and acts as a mantle to protect the discharge area against the transmission of flame. This condition is maintained more certainly by the contraction of the discharge area at the top of the cone, which increases the velocity of discharge and completely divides the intake air from the gases discharged from the lamp, without making it necessary to insert a solid partition to accomplish this purpose. In this respect the lamp represents the most perfect construction of any safety lamp now made.

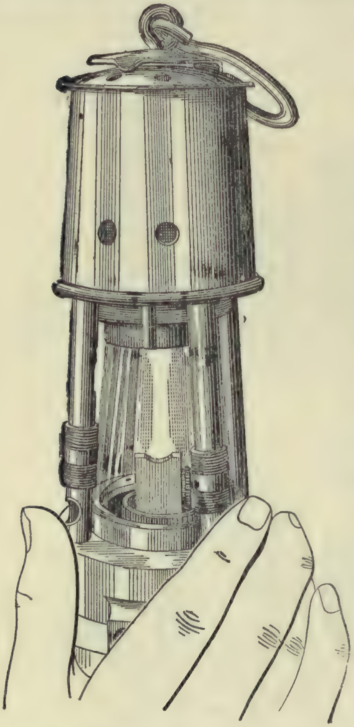


Fig. 33.—Showing Manner of Testing for Gas with the A-H-G Lamp

Mr. Ashworth recognized that "Theoretically the Gray arrangement was the best for obtaining accurate indications of the state of the air close to the roof; but practically it was wrong, because when gas entered the tubes it was compelled to pass through the lamp before any fresh air could enter."* To overcome this difficulty one or more of the Gray inlet tubes of the A-H-G lamp were provided,

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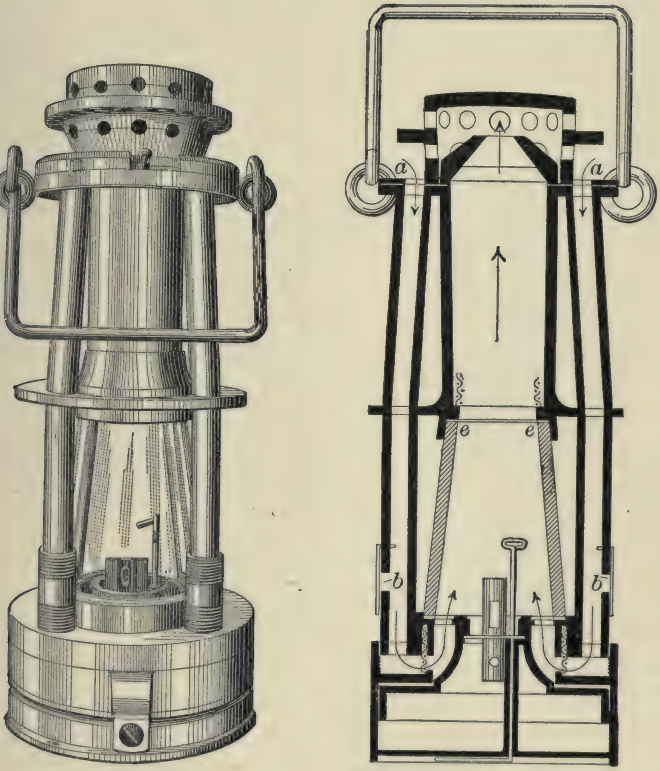
* Mining Accidents, Abel, page 73.

at Mr. Ashworth's suggestion, with openings at their base that could be closed with slip muffs, as shown in the figure. This form was particularly convenient and practical when making a test for gas, because with the slides pushed up



View Section

Fig. 34.—Standard A-H-G Lamp

and the openings partly covered by the forefinger and thumb, as shown in Fig. 33, it was possible to so control the admission of the air and the gas as to prevent the extinction of the flame.

Fig. 34 shows the standard A-H-G lamp. In this lamp the outer bonnet is omitted, the inlet tubes being here carried to the top of the lamp, where they terminate in the plate to which the bale of the lamp is shown as attached. Above this is another closely fitting plate provided with holes corresponding to the inlet tubes below; this is the cut-off plate for opening or closing the tops of the tubes. A small pin fixed in the lower plate fits the cut shown in the upper one and limits the movement of the cut-off plate. When the tops of the inlet tubes are closed and the slides at the bottom of the lamp pushed up, air enters the lamp through the lower openings, but when testing for gas close to the roof the lower openings are closed and the cut-off plate shifted to admit air at the top of the tubes. The plain brass cylinder shown between the standards above the glass chimney is the inner bonnet shown on the right in Fig. 32, and has the same form as that bonnet, terminating in a truncated cone within the hood that covers the top of the lamp, as shown in the sectional view on the right, Fig. 34.

Fig. 35 shows two of the most recent forms of the A-H-G lamp. These have a single inlet tube, in each case, there being but three standards instead of four as in previous lamps of this type. Two of these standards are made of light No. 7, B.W.G. brass wire, so as to reduce to a minimum the obstruction of the light by the uprights. The illuminating power of these lamps is high, being given as .79 candle power. The resistance of the lamp to explosive currents having a high velocity is remarkable. The lamp is said to have successfully withstood a current velocity of 6,000 feet per minute, which is about double the velocity at which other lamps have been tested. The A-H-G lamps are generally designed to burn ordinary sperm or lard oil, but are sometimes fitted with oil vessels specially designed to burn some form of methylated spirits, alcohol, naphtha or benzoline.

In what manner Mr. Hepplewhite's name became connected with this lamp does not appear. Mr. Hepplewhite was mine inspector at the time when Mr. Ashworth and Mr. Gray brought out their joint lamp under the name of the Ashworth-Hepplewhite-Gray lamp, and it may have been in recognition of some suggestion of improvement or use of the lamp.

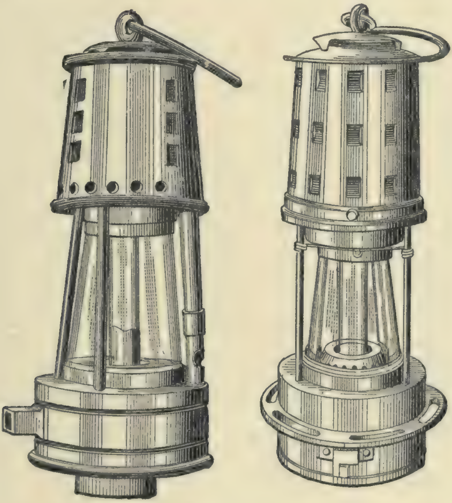


Fig. 35
Improved A-H-G Lamps

166. The Beard Deputy Lamp.—This lamp is a Marsaut lamp designed by the author on the Eloin principle, for the purpose of producing a safe working lamp that would give at once a good illumination and permit the use of the Sight Indicator for revealing the gaseous condition of the mine air. The indicator is shown in position in the lamp, Fig. 36, but will be described later (Art. 204). This lamp should be bonneted when used for general work; the unbonneted lamp, Fig. 36, is adapted to the work of testing for gas. Both as a working and a testing lamp it gives excellent results. With two gauzes the bonneted lamp will withstand a current velocity of 2,000 feet per minute, while with three gauzes it can safely be used in an explosive current of 2,500 feet per minute. Its illuminating power is .75 for a two-gauze, and .60 candle power for a three-gauze lamp burning a good quality of sperm or colza oil.

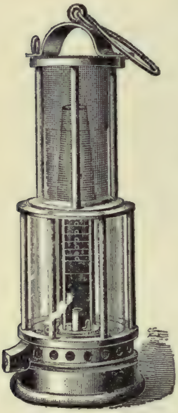
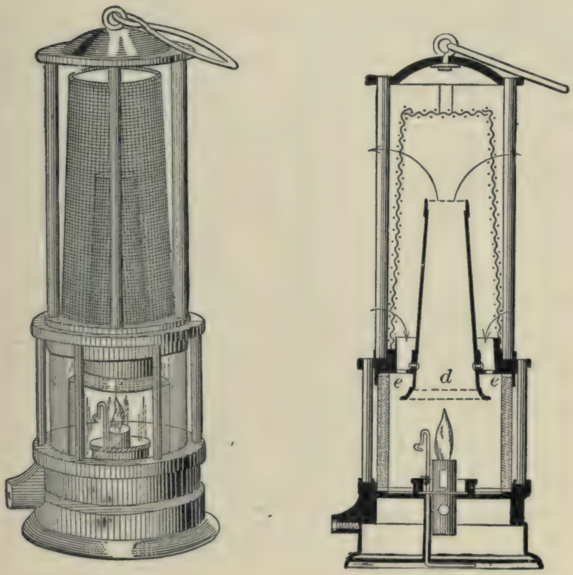


Fig. 36
Beard Deputy Lamp

The advantage derived from the use of this lamp is the increased illumination, freedom from smoking and the consequent bedimming of the glass and obstruction of the gauze. With the indicator in the lamp the slightest change in the gaseous condition of the air is made known quickly by the bright incandescence of the looped wires shown above the flame. These wires are called the percentage wires, and show the exact percentage of gas present in the air at the moment and place of exposure. This indication being made on the normal working flame of the lamp, without its being necessary to draw down the flame, is a *sight indication* that is always present; hence, the use of this lamp avoids the danger arising from any lack of judgment on the part of the man in charge of the lamp as to whether a test is necessary, and his disposition to assume that a place is clear of gas, which has been the cause of many fatal accidents.

167. The Mueseler Lamp.—This lamp in its simplest form consists of an ordinary Clanny lamp, in which is inserted a conical sheet-iron chimney. There are two general types of the Mueseler lamp, known as the English Mueseler, Fig. 37, and the Belgian Mueseler, Fig. 38. These differ only in the dimensions of their metal chimneys.



View Section

Fig. 37.—English Mueseler Lamp

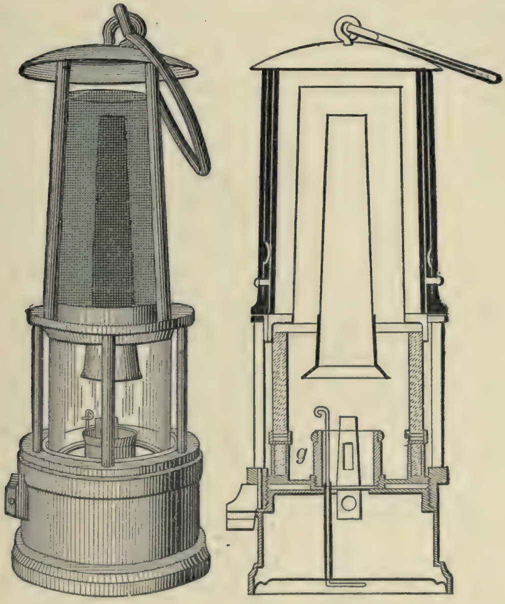
The English chimney is broader and shorter and its bellmouth wider than that of the Belgian lamp, in which, at times, the mouth is made straight instead of flaring, as shown in Fig. 38.

In each of these lamps the air enters, passing through the lower portion of the gauze above the glass chimney and descending to the flame; the burnt air and gases pass upwards through the central tube or chimney and escape through the upper portion of the gauze. The chief characteristic of the Mueseler lamp is the security it presents against the transmission of the flame due to an explosion within the lamp. In this respect the lamp has perhaps no superior. The force of the explosion is mainly spent within the sheet-iron tube, and is exerted downwards, owing to the conical shape of the chimney. The central chimney produces a strong upward draft and gives this lamp a higher illuminating power than the Clanny, but it is still far inferior to the Marsaut in this respect, being only from .30 to .40 candle power. In Belgium a royal edict makes the legal lamp of the following dimensions with respect to its chimney:

	Millimeters	Inches
Interior diameter at top of upper cone. . . .	10	.39
" " at base of upper cone. . .	25	.98
" " at base of expansion . . .	30	1.18
Height of chimney (total)	117	4.61
" " expanded base.	6	.24
" " base of chimney above wick tube	22	.87
" " top of chimney above gauze diaphragm	90	3.54

The tests of The Royal Accidents Commission proved that the Belgian lamp constructed with the above dimensions was much superior to the English Mueseler, whose central chimney was generally shorter and wider and set higher in the lamp. While the Belgian lamps tested by the commission successfully withstood an explosive current having a velocity of 2,857 feet per minute, the English lamps tested at the same time failed in a current velocity of only 1,000 feet per minute.

In the genuine Mueseler lamp the combustion chamber is divided at the top of the glass chimney by a horizontal diaphragm of wire gauze, its purpose being to prevent, as far as possible, the flame of the burning gases in the lamp ascending between the central chimney and the outer gauze chimney, which would heat the gauze to a dangerous degree. This horizontal gauze diaphragm is shown at *e*, Fig. 37. It is evident that the Mueseler lamp, owing to its construction, is more dependent on a uniform and unchanging circulation in the lamp than perhaps any other type of lamp. The reason for this is that the upper portion of the space between the central chimney and the outer gauze becomes filled with gas that may be highly



View **Section**

Fig. 38.—Belgian Mueseler Lamp

explosive, especially on the addition of a little air. A slight inclination of the lamp from the vertical, or a deflection of the air-current striking the lamp, may cause this gas to enter the combustion chamber, or in certain cases may even cause its ignition in the gauze cap outside of the chimney, which would present a greater danger than an explosion in a Davy or a Clanny lamp. Owing to the same conditions the Mueseler lamp is easily extinguished when it is inclined at a slight angle from the vertical and requires careful handling, because the products of the combustion, filling the upper portion of the lamp are at once thrown down upon the flame of the lamp on the slightest diversion of the uniform circulation.

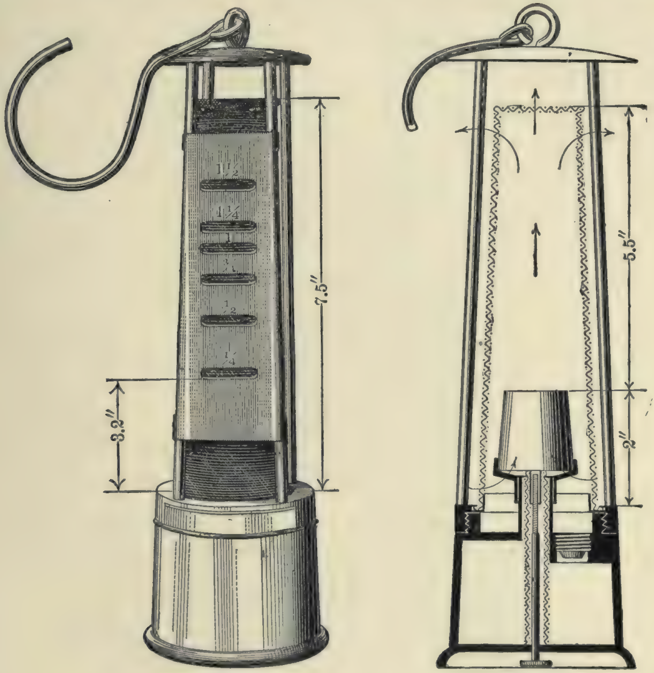
As compared with the Marsaut lamp the Mueseler gives but about two-thirds as much light; it will not withstand the current velocity that a three-gauze Marsaut will withstand; it is extremely sensitive to oblique air-currents or any inclination from the vertical, which may cause the extinction of the light or render the lamp under possible conditions more unsafe than a common Davy or Clanny lamp.

SPECIAL SAFETY LAMPS

168. There are a large number of lamps designed for special purposes or making use of special means. Of the former class may be mentioned the Pieler, the Chesneau, the Stokes alcohol lamp, the Clowes hydrogen lamp, and the Beard-Mackie lamps, all of which save the last-named make use of special flames for the purpose of testing for gas in mines; of the latter class of lamps the Wolf lamp is a prominent type, being designed to burn a special illuminant, and having beside other special features.

169. **The Pieler Lamp.**—This lamp (Fig. 39) was designed to test for gas by means of the alcohol flame, since

this flame has been found to be extremely sensitive to the presence of gas. The oil vessel is constructed to burn alcohol. As shown in the sectional view a cylindrical hood or shade is arranged about the flame; the height of the shade being such that the tip of an ordinary sized alcohol flame will just reach the top of the shade when no gas is present. In appearance the Pieler lamp resembles a tall Davy. The gauze of the lamp is about 7½ inches high in order to accommodate the reach of the alcohol flame when gas is present. When the lamp has no bonnet a fixed scale is attached to the lamp standards



View Section

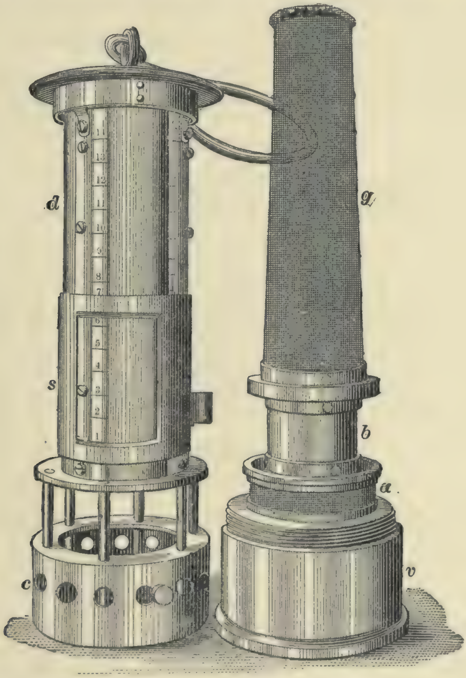
Fig. 39.—The Pieler (Alcohol) Testing Lamp

and provided with narrow slots to observe and measure the height of the flame cap. Each slot is marked as in the figure to indicate the percentage of the gas. If the lamp is bonneted, a glass window is inserted in the bonnet and the same scale is marked on the glass.

Like all alcohol lamps the Pieler is very apt to be extinguished when making a test, this often occurring before the test has been completed, which is a great annoyance and makes this lamp impracticable for the use of fire bosses when examining a mine. The lamp is only useful for the detection of small percentages of gas, since anything over 2 per cent. of gas in the air will cause this lamp to fill with flame; the top of the metal shield corresponds to 2 per cent. of gas. Owing to the large gauze area and the increased danger of the transmission of flame, the lamp requires careful handling and should only be intrusted to an experienced person, who should exercise due care not to expose the lamp to a body of accumulated gas. When making a test to determine the percentage of gas in an air-current, care must be taken to protect the lamp from the direct force of the current. Within the brass oil vessel is placed an amount of cotton that will absorb and retain the alcohol in case the lamp is overturned, but when the cotton is sufficient for this purpose its absorptive power is so strong as to interfere with the heights of flame cap and the correct determination of the percentage of gas present in the air. The oil vessel is closed tightly by a screw plug and a thin leather washer, as shown in the sectional view.

The Pieler lamp was designed by an Austrian mining engineer whose name it bears; it has been most largely used on the continent in Austria, Germany, Belgium, and France. The lamp is unsafe when the velocity of the air-current exceeds 750 feet per minute, unless carefully screened, when it may withstand a current velocity of 900 feet per minute, provided the quantity of gas present in the air is small.

170. The Chesneau Lamp.—This lamp like the Pieler



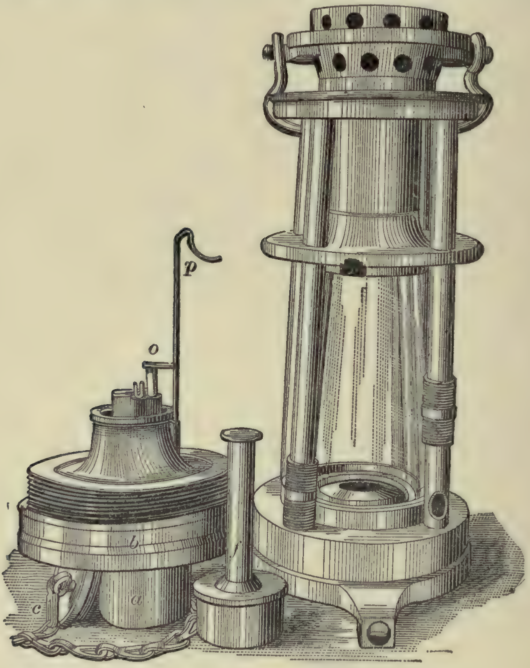
Bonnet Removed Lamp and Chimney
FIG. 40.—The Chesneau (Alcohol) Testing Lamp

is an alcohol lamp, designed for the purpose of testing for gas in mines; the lamp is much safer in gas than the Pieler. The inventor, G. Chesneau, an eminent French mining engineer, professor of Mining at the National School of Mines, Paris, and secretary of the French Firedamp Commission, has given much thought and study to the formation of flame caps in gaseous atmospheres as a means of measuring the percentage of gas present. The experiments of MM. Mallard and Le Chatelier, members of the same commission, first drew attention to the higher caps given by the alcohol flame. The Chesneau lamp (Fig. 40) differs from the Pieler in the manner in which the air is admitted into the lamp through the double-gauze openings *a* at the bottom of the chimney, shown immediately above the oil vessel on the right of the figure. When the bonnet shown on the left is screwed to the lamp, the entering air passes through the openings *c* before it reaches the gauze *a*. Setting on top of the base ring that holds the gauze *a* is a hollow sheet-metal cylinder that surrounds the flame and corresponds to the metal shield in Fig. 39, acting with the base ring of the upper gauze *g* as a shade, to the top of which the tip of the flame is adjusted in pure air. The main gauze *g* rests on the upper flange of the shield *b*, the whole being held in place by the sheet-iron bonnet *d*. The gauze in this lamp is a much finer mesh than the standard Davy gauze, since it has 1,264 openings to the square inch instead of 784. The bonnet *d* is provided with a window of mica or isinglass, on each side of which is a white scale graduated, the one to read percentages and the other centimeters. Surrounding the bonnet is a sliding shield *s* that assists in obtaining a closer reading of the scale, as this shield can be set to the exact tip of the flame cap and the reading then taken. The brass oil vessel contains cotton, but in much less quantity than in the Pieler lamp, so as to avoid the impairing of the formation of the flame cap by the absorption of the alcohol to such an extent as to impede its flow.

The Chesneau lamp has been found to withstand a current velocity of 11 meters per second, or 2,160 feet per minute, in an explosive mixture of gas and air. One peculiar difference between this lamp and the Pieler is the time required for each to assume a normal state or condition of the flame, so that the flame caps will indicate by their height the correct percentage of gas present. When a lamp is exposed to an atmosphere containing a high percentage of gas, it heats rapidly and retains this heat for some time after being withdrawn from the gas. Owing to the volatile character of the alcohol burned in these lamps, the temperature of the lamp is sufficient for a considerable time thereafter to vaporize the spirit, producing an artificial gaseous atmosphere within the gauze, which increases the height of the flame cap and renders the lamp practically useless for making an accurate test. It is stated that while the Pieler lamp requires about 30 minutes to assume a normal state, the Chesneau lamp regains a normal condition in 30 seconds, but this will depend largely on conditions and the length of time the lamp was exposed to gas, and the degree of heating. The ready vaporization of the more volatile illuminants renders them unreliable for the purpose of testing for gas in mine workings where the lamp is often necessarily exposed continuously to a gaseous atmosphere, and the consequent heating of the lamp causes it to give indications higher than the actual.

171. **The Stokes Alcohol Lamp.**—In this lamp Mr. A. H. Stokes, inspector of mines for the Midland district, has endeavored to supply an alcohol flame, as desired, in a lamp burning ordinary sperm oil or colza. For this purpose he chose the Ashworth-Hepplewhite-Gray lamp shown in parts in Fig. 41. This lamp is identical with that already described and illustrated in Fig. 34, except for a small tube that passes up through the oil vessel of the lamp and

the arrangement of a screw thread in the bottom of the lamp to receive and hold the small alcohol lamp *a*. This alcohol lamp is thus detachable from the oil vessel *b*, and the cover *c* is then screwed in its place to close the opening. The lamp *a* is provided with a long neck that reaches to the level of the top of the wick tube of the oil vessel *b* when screwed in place. The top of the tube through which this long neck passes is closed automatically by the stop *o* when the lamp is withdrawn; this stop is operated by a spring, being pushed upwards by the lamp *a* as it is screwed in place and forced back by the action of the



Oil Vessel and Alcohol Lamp Bonnet Removed

Fig. 41.—The Stokes Testing Lamp

spring. A spiral groove causes the stop to swing to one side as it rises, so as not to interfere with the alcohol flame. The latter is ignited by the oil flame, which is then extinguished by drawing down the wick with the pricker *p*, leaving the alcohol flame alone in the lamp. After making the test the oil wick is again raised and ignited and the alcohol flame withdrawn. When the small lamp *a* is not in use it is protected by the cap or cover *f*, which is screwed to the top of the lamp. The oil lamp is shown here with a flat wick.

Other attempts have been made by Ashworth, Chesneau, and others to convert the common types of oil-burning lamps that were considered safe lamps into testing lamps burning alcohol; but owing to the extreme sensitiveness of the alcohol flame, the volatile character of the fluid, and the generally unfavorable conditions for testing in the mine, these attempts have met with but partial success.

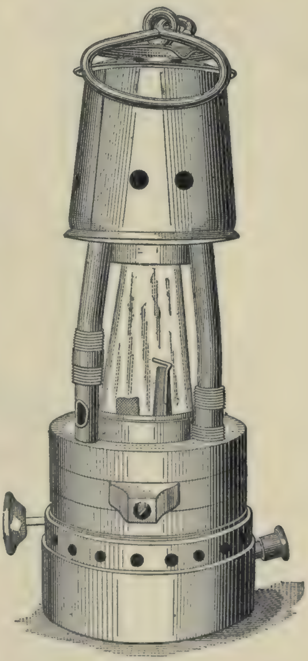
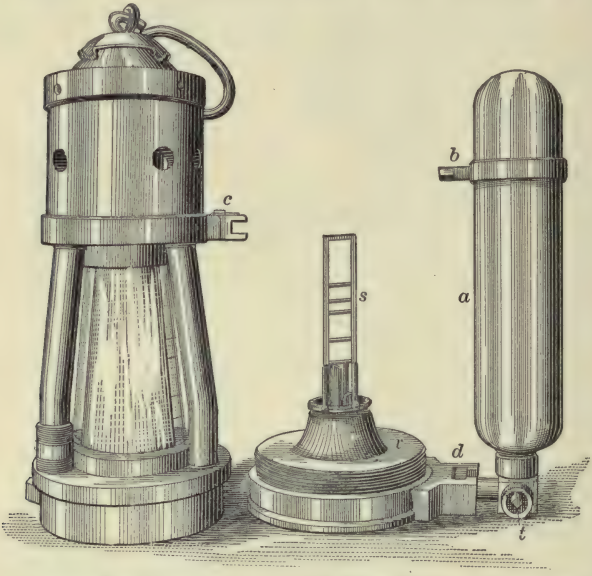


FIG. 42.—The Ashworth Tester, Oil-Alcohol

172. The Ashworth Tester.—This lamp has a purpose similar to that of the Stokes lamp just described, being indeed the earlier lamp. It is not, however, as light and portable as the above lamp. It has two vessels, as shown in Fig. 42, the upper one for oil and the lower for alcohol, the neck of the latter passing up through the oil vessel. The lamp is a combined Ashworth-Gray type, all the features of which have been described as those of the A-H-G lamp, Fig. 32 (Art. 165). The oil-wick tube stands up higher in the lamp than the alcohol burner, and is utilized as a shade to screen the eye from the body of the alcohol flame when observing a cap.



Bonnet Removed Oil Vessel and Gas Cylinder

Fig. 43.—The Clowes Hydrogen Lamp

173. The Clowes Hydrogen Lamp.—This lamp is shown in parts in Fig. 43, a section of the oil vessel being shown in Fig. 44. It consists of a short-pattern A-H-G lamp (Fig. 32) into the oil vessel of which has been inserted a fine copper tube having a capillary bore for the passage of the hydrogen gas. This tube *h* (Fig. 44) extends from the opening *o* on the side of the oil vessel up through the vessel, and its upper end terminates at the side of the wick tube *w* even with its top. The conical nozzle of the gas cylinder *a* (Fig. 43) fits into the opening *o* (Fig. 44) and is held in place by a union screwed to the lamp, making a gas-tight joint. The nipple *n* screws into the neck of the oil vessel and holds in place both the wick tube *w* and the collar *c*, to which is attached the scale *s* (Fig. 43) for gauging the height of the flame. A flat wick is used in this lamp and is raised and lowered by the usual form of pricker.

In Fig. 43 the hydrogen cylinder *a* is shown as connected to the side of the oil vessel *v*. If the valve in the lower end of the cylinder be now opened by a key fitted at *t*, hydrogen will flow from the cylinder, where it is compressed to a pressure of 1,800 pounds per square inch, to the tip of the tube *h*, where it is ignited by the oil flame when this is burning. When putting the lamp together the cylinder is first detached from the oil vessel and the latter screwed into the base ring of the chimney. The hook or claw *b* is then made to engage the prongs at *c*, after which the final connection is made by a screw nipple at *d*. The

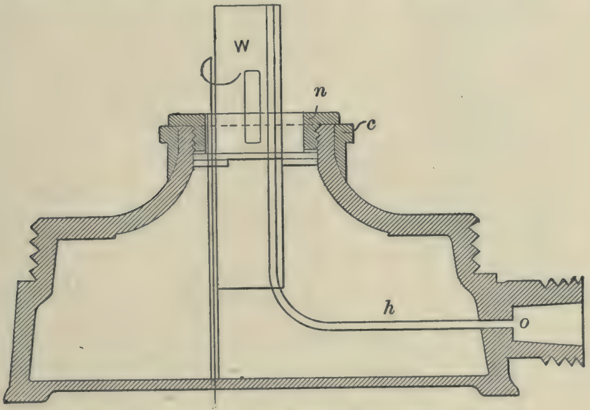


Fig. 44.—Section of Clowes Hydrogen Lamp

hydrogen cylinder *a* of this lamp has been tested by hydraulic pressure to 3,000 pounds per square inch.

When making a test the manipulation of the hydrogen flame is the same as that previously described in the case of the alcohol flame of the Stokes lamp. The height of the flame cap is measured by the scale *s* attached to a ring *c* (Fig. 44) that fits over the neck of the oil vessel and is held in place by the nipple of the wick tube. The lowest bar of this scale (see Fig. 63) is even with the top of the wick tube; the second bar determines the height of the standard flame, .4 inch. The four bars above this indicate respectively .5, 1, 2, and 3 per cent. of gas being set at .9, 1.1, 1.4, and 2.3 inches respectively above the top of the wick tube. At these heights each bar is exactly .2 inch below the tip of the corresponding flame cap, which causes the bar to appear as a black line across the flame. The position of the bar is thus clearly discernible, but allowance must always be made of .2 inch when observing the cap. Like the alcohol flame the hydrogen flame must be carefully handled to avoid its accidental extinction, though it is not as sensitive in this respect as the flame of alcohol. Cylinders of different capacity are furnished as desired, but the small pocket cylinder *a* (Fig. 43) charged to 120 atmospheres, which is the most usual charge, contains 1,080 cubic inches of hydrogen and will maintain the standard hydrogen flame a little over two hours, permitting 200 tests to be made. When empty the small cylinder is recharged from a large stock cylinder, which must be kept on hand. The weight of the lamp, filled with oil and the cylinder complete, ready for use, is 4 lb. 14 oz. brass, or 2 lb. 7 oz. aluminum. The Clowes lamp will determine with certainty the presence of .5 per cent. of gas, but below this point the cap is hazy and uncertain in its outline, and the percentage of gas must be estimated more or less roughly. The hydrogen flame is used for determinations up to 3 per cent., while the oil flame is used as usual for determinations from 3 to 6 per cent. (Art. 213).

174. The Beard-Mackie Lamps.—These are lamps that have been specially designed to hold the Beard-Mackie sight indicator, and are in most cases adapted to its use. Such are the Eloin-Marsaut lamp designed by the author (Fig. 36), the special A-H-G lamp designed by John Davis & Son, Derby, England (Fig. 45), a special French model lamp designed by Paul Renaud, Paris, France, and others. These lamps have, in general, a glass $3\frac{1}{2}$ in × $2\frac{3}{8}$ in., and are arranged to admit the air below the flame, so as to secure a more uniform condition within the lamp and give an atmosphere that will represent accurately the gaseous condition of the air surrounding the lamp. This is a most important point in designing a good testing lamp, as otherwise the results obtained are erroneous, although the indications may themselves be extremely accurate. This is one of the greatest faults of a bonneted testing lamp; under many of the conditions common in mine workings, the bonnet, by restricting the free circulation of air through the lamp, prevents the condition within the lamp from representing accurately that of the outside air. The Beard-Mackie lamps aim to avoid this fault by establishing and maintaining in the lamp a strong upward draft, while the necessary protection at the top of the

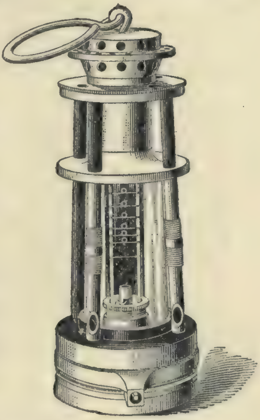


FIG. 45.—Beard-Mackie Lamp (English Model)

lamp is secured either by the multiple Marsaut gauzes or the Ashworth shield (Fig. 32). The principle of the sight indicator insures an accurate sight determination at all times to within one-half of one per cent. and ranging from .5 to 3 per cent., owing to the bright incandescence of the six looped percentage wires, which indicate by their successive incandescence 0.5, 1, 1.5, 2, 2.5, and 3 per cent. of gas present in the air. The single straight wire above the flame is the *standard wire* for setting the flame to the proper height when the lamp is in pure air. The lamp glass is provided with a black enameled strip that furnishes a good background for observing the indicator. The construction and use of the indicator will be explained more in detail later (Art. 204).

175. The Wolf Lamp.—The usual form of this lamp for general mine work is shown in Fig. 47. On the left is the lamp surmounted by its combined glass and gauze chimney, while on the right is the corrugated steel bonnet firmly attached by the standards to the ring by which it is screwed to the lamp vessel. In the foreground is shown detached from the lamp the special friction igniter *i*, of which a detail sketch is shown in Fig. 46. The igniter is shown in position in the lamp in Fig. 48. It consists of a box *i*, into which is inserted from the top a small rod or pull bar *f*. To the upper end of this rod, as shown by the dotted lines, is attached a thin ribbon of spring steel bent double; this is the scraper by which the friction match is ignited. The right arm of the scraper is provided with sharp teeth

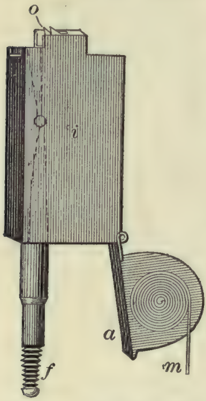
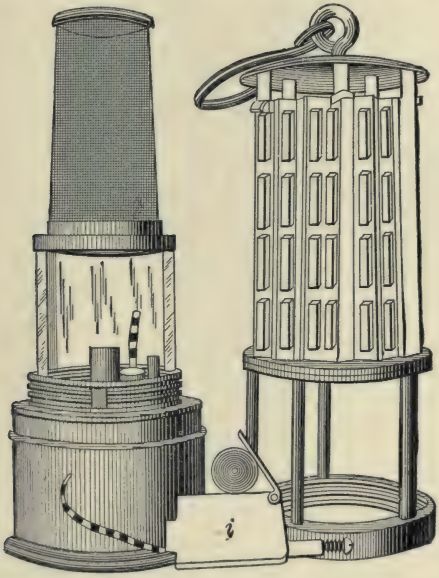


Fig. 46.—Igniter Detached from Lamp

at its upper end, and when the rod *f* is pushed up these teeth are pressed into the match ribbon *m*, which is threaded upwards through the opening *o*. The match is thus carried up into position for lighting. It is here shown coiled on a hinged plate *a*, which is turned down for its insertion. The match consists of a waxed paper ribbon, containing in its folds small nubs of a fulminate, about three to the inch. The spring holds the scraper against the match ribbon and keeps it in place. When, now, the pull bar *f* is drawn down quickly, the cap is exploded by the teeth of the scraper and the wax paper is ignited and burns till extinguished at the top of the box, the momentary blaze kindling the lamp wick.



Lamp and Chimney Bonnet Removed

FIG. 47.—The Wolf (Naphtha-Benzine) Lamp

While there may be times when it would be an unquestionable advantage to be able to relight an extinguished lamp, the means to this end should be such as do not invite danger at another time. The particular danger in this case arises from the kindling of a flame in an atmosphere at times heavily charged with an explosive vapor, which may cause a flash of flame to pass through the gauze of the lamp and ignite gas outside of the lamp. So volatile is the naphtha burned in this lamp that but a few seconds are required to produce a dangerous flash (Art. 187), especially if the gauze of the lamp be dusty or the mine air laden with gas and dust. The writer is not questioning the

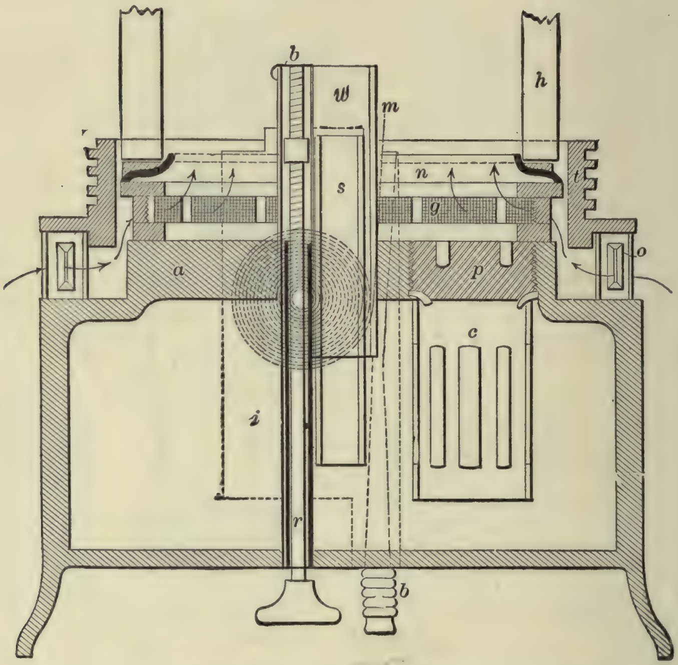


FIG. 48.—Detail Section of Oil Vessel of Wolf Lamp

advantage of relighting a lamp in case of necessity, but would emphasize the danger in a gaseous mine when the temptation to extinguish and relight a lamp is thus placed promiscuously in the hands of boys and irresponsible miners. Again, it may chance that the same blow that extinguished the lamp may have broken the glass or injured the gauze, in which case the relighting of the lamp would be a positive danger, of which the miner is wholly unconscious.

The construction and arrangement of the various parts of the oil vessel of this lamp are shown in detail in Fig. 48. The lamp is constructed to burn naphtha (benzine). This fluid is highly explosive; it vaporizes rapidly and requires the utmost care and caution in handling, to avoid accidents when filling the lamps. The body of the font is made of sheet steel and is provided with an extra heavy brass plate *a*, which forms the top of the vessel. The only opening into the oil vessel beside that for the wick tube *w* is that closed by the screw plug *p*, having the same thickness as the top plate *a*; this plug is removed by a forked key inserted in the two holes shown in the top of the plug. Owing to the explosive character of the naphtha burned in this lamp, it is necessary to fill the font first with a specially prepared filling cotton cut in strips about an inch wide. About two-thirds of an ounce of this cotton is used in a lamp at one time, a cylindrical cotton spreader *c* being inserted to hold it in place and to form a well from which the surplus fluid is drained after filling the lamp and before closing the font. A leather washer is inserted under the plug to prevent leakage. The wick in this lamp is held in a sheath *s* that slides up and down within the wick tube *w*, being operated by the screw on the end of the rod *r*, which passes through the small collar shown attached to the upper end of the sheath *s*. The rod *r* is itself incased in a brass tube that passes through the oil vessel. A small lid *b* closes the top of this tube, and when removed permits the sheath *s* to be taken out for renewing the wick. Resting on the shoulder of the font and firmly attached to it is a steel corrugated ring provided with openings *o* for the admission of air to the lamp, as indicated by the arrows, the air being deflected upwards and entering the combustion chamber through the protected openings in the gauze ring *g*. Resting above the corrugated ring *o* to which it is firmly attached is the screw ring *t*, forming the means of securing the bonnet, which likewise holds in place the glass chimney *h* and the gauze above. As shown in the figure, the glass chimney rests on a washer that fits over a spring ring *n* for the purpose of making a tight joint between the chimney and the lamp. This ring has at times been inadvertently omitted in putting the lamp together, the glass chimney then resting on top of the gauze ring *g*, which might cause the lamp to fail in gas. The igniter box *i* (Fig. 46) is inserted in a special well hole prepared to receive it, being sunk into the body of the font but closed to the oil chamber. Its position is shown by the dotted lines in Fig. 48, the end of the burned match being shown at *m*.

After placing fresh filling cotton in the lamp the latter is filled with as much naphtha as the filling cotton will absorb. Only 70-degree naphtha must be used, and this should be placed in the lamp by means of a special filling apparatus consisting of a tank holding, say 20 gallons of the fluid. One form of filling tank used is shown in Fig. 49. A small rotary pump is used to fill the tank through the pipe *a*; from this tank the fluid is forced into the glass cylinders *b*, of which there are three attached to the side of the tank. Each cylinder holds sufficient oil to fill one lamp. A glass gauge *c* shows the level of the oil in the tank; dripping pans *d* are placed beneath each filling cock.

Great care is necessary to keep both the wick and the filling cotton free from oil and grease, and they therefore require to be renewed from time to time that the fluid absorbed by the filling cotton in the lamp will rise readily to the flame and the illuminating power of the lamp be not impaired. Only specially prepared cotton must be used in the lamp. When the lamp is to be filled the screw

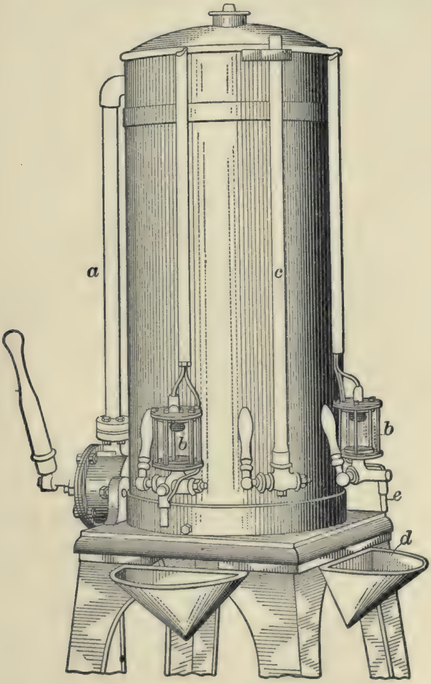


Fig. 49.—Tank for Filling Wolf Lamps with Naphtha

plug is removed by means of a forked key, and the lamp held so that the nozzle *e* of the faucet reaches well down into the lamp. When the faucet is now opened the contents of the glass cylinder flows into the lamp and is absorbed rapidly by the cotton till the latter has taken up all it will hold. The flow is stopped automatically as soon as any surplus fluid accumulates in the lamp vessel. The faucet is then closed and the lamp removed, the glass cylinder again filling automatically upon the closing of the faucet. The surplus oil is drained from the lamp and the plug again screwed in its place, having a washer beneath.

The principal features of the Wolf lamp are the self-lighting attachment, of which mention has been made; the increased illuminating power of the naphtha, which is rated in this lamp as being 1-candle power when first lighted, reducing to .8 towards the close of the shift; a magnetic lock, which it is claimed cannot be opened outside of the lamp room where a strong magnet is required to loosen the fastening. Like all closely bonneted lamps, this lamp goes out when exposed to a body of sharp gas.

LOCKS FOR SAFETY LAMPS

176. One of the important features of a safety lamp is the lock, which prevents the lamp being opened while it is in the mine. Locks have been designed from time to time with different purposes in view; some of these afford protection only against the lamp being opened inadvertently; others prevent the lamp being opened without detection by the lampman having the lamps in charge; others are so arranged that the lamp cannot be opened without its flame being extinguished by so doing; and in another class the lamps are locked in such a manner that they cannot be opened except through the agency of a strong electro-magnet, or a powerful air-pump which cannot in general be found outside of the lamp room.

177. Requirements of Locks for Safety Lamps.—A chief requirement is simplicity of construction and absolute certainty of action. It is not sufficient that a lamp be made secure against being opened inadvertently, because all men are not honest. It is sometimes inconvenient and is often considered inadvisable to construct a lamp in such a manner that it cannot be opened and the light retained. When everything is considered, that form of lock that is simplest, most quickly adjusted, and will most certainly reveal any attempt to open the lamp is the lock that best meets the practical requirements in a mine. This seems to be the case with the common *lead-plug lock*.

178. Kinds of Locks.—The *screw bolt* or *screw plug* is a very common form of lock in mines, where the conditions with respect to gas are not such that rigid regulations have been enforced. In many such mines mixed lights are used, and it is a common thing for a miner to open his safety, since he is using his naked lamp much of the time. This form of lock is shown on the Davy and Clanny lamps in Figs. 21 and 25. The screw bolt forming the lock has either a square or a flattened end that can be turned by either a square or a split key. When a key is not at hand, the miner often improvises one by splitting a nail; no ingenuity is required to open this lock. The lock represents the first of the different classes of locks mentioned in Art. 176.

The **lead-plug lock** represents those locks belonging to the second class, and which cannot be opened in the mine without detection when the lamp is returned to the lamp house. This is the simplest form of lock in use, and on this account is generally preferred by mine officials. Owing to its possessing no mechanism, it offers less inducement to men and boys of a curious turn of mind, and is less frequently disturbed than more intricate locks, which always invite investigation, with no other purpose than a test of ingenuity. There are different forms of this lock, one of which is shown in Fig. 50, and consists of a hasp attached by a hinge to the base ring *a* of the lamp chimney. When the oil vessel *v* is screwed in place the hasp closes over a lug fixed to its side and having a hole *c* through which the lead plug is passed. A special machine is generally used to clamp the plug and this is furnished with a special print or with the date if desired.

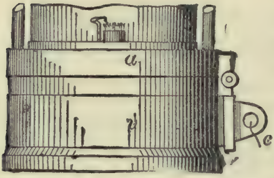


FIG. 50.—Oil Vessel Fitted with Lead-plug Lock

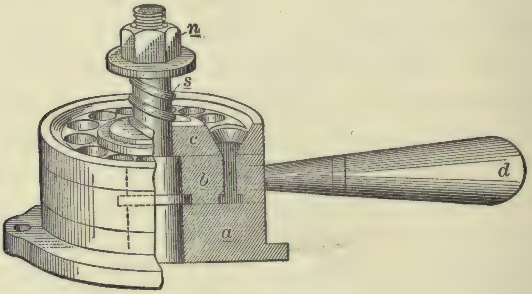


FIG. 51.—Improved Rivet Mold

In Fig. 51 is shown an improved form of rivet mold made in three sections. The lower section *a* is fastened to a bench; the two upper sections *b* and *c* are removed, heated, and replaced, being held together by the force of the spring *s* and the nut *n*. The melted lead is poured into the top of section *c* and fills the holes, which are seen cut away, in the section. Allowing a moment for the metal to cool, the handle *d* is swung back and forth to shear off the rivets in section *b* from the surplus metal in section *c*. The upper section *c* is prevented from rotating when the handle is swung to and fro by a projection on the central axis that fits into a groove in the section. The upper sections are now removed and the rivets fall out. A hot mold is required to produce good rivets. The mold contains about 20 holes.

The **protector lock** (Fig. 52) is so called because it prevents the lamp to which it is attached being opened without extinguishing the light. In the figure the brass plate *c* screwed into the base ring *a* carries the glass chimney *b* and at its center is threaded to receive the muff or collar *m* screwed over the round wick tube *w* attached to the oil vessel *v*. The muff *m* forms the extinguisher; it is provided at its lower end with two flanges *f*. The end of the lock-bar *l*, shown in section at *e*, is the arc of a circle and fits against the collar and prevents it from turning, by

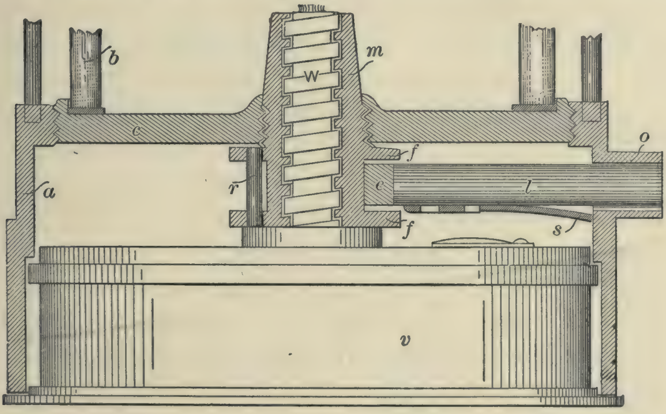


Fig. 52.—Sectional View of Protector Lock

engaging the rivet *r* fixed in the flanges of the collar. The lock bar is inserted into the opening in the base ring at *o*, from the inside, before the lamp is in place. To do this the spring *s*, which is riveted to the under side of the bar, is pushed up so as to slide into the opening. When the lock is in this position, the flanges *f* of the collar *m* are free to pass the end of the bar *e* and the rivet *r* can turn freely. The collar *m* is first screwed on the wick tube *w* and the lamp lighted. The lighted lamp is then passed up into the base ring *a*, the muff or collar *m* screwing into the plate *c*, as shown in the figure. When all is tight the lock bar *l* is pushed in till its end strikes the collar *m*, and the spring *s* drops and holds it fast on the inside of the lamp. If, now, the oil vessel be unscrewed, the lock bar will prevent the collar from turning, and the wick tube will screw out of the muff, the light being certainly extinguished by the operation. The lamp shown in the figure is arranged to burn benzine.

Other locks of this class are so arranged that the unscrewing of the oil vessel from the lamp brings a hood or extinguisher over the flame, which smothers the flame completely before the top of the lamp can be removed.

The **magnet lock,** as its name implies, is operated by a powerful magnet at the lamp house or lamp station. There are different forms of the lock; that shown in Fig. 53 is the form adopted in the Wolf lamp. In this figure only the base ring *a* of the lamp is shown, with the two poles N and S of the large magnet used to operate the lock and open the lamp. When the two nubs on the base ring are in contact with the poles of the large magnet, as shown in the figure, the small poles *b* and *c* of the lamp are powerfully magnetized, the magnetism passing through the spring *e* magnetizes the pawl *p*, the point of which is then drawn towards the pole *b*, which throws the tooth *p* of the pawl back within the lamp ring and releases the lamp so that it may be unscrewed from the ring. When the lamp is removed from the poles of the magnet, the spring *e* acts to throw the tooth of the pawl forwards, so that when the oil vessel of the lamp is again screwed into the ring it is locked automatically.

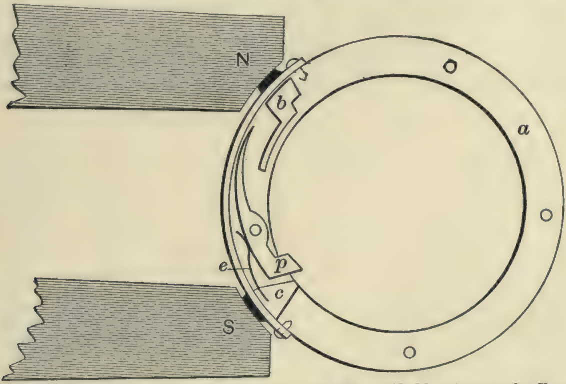


FIG. 53.—Showing the Operation of the Wolf Magnetic Lock

Another form of magnet lock used by the American Safety Lamp Co., in a lamp that very much resembled the Wolf lamp, is that shown in Fig. 54. Here the oil vessel *v* is locked in the base ring *a* of the chimney by the steel bolt *p*, which is forced upwards by the spring *c*. When the plug of soft iron *b* is in contact with the end of a magnetized bar, the bolt *p* is drawn down and the lamp released so that it may be unscrewed from the lamp ring *a*.

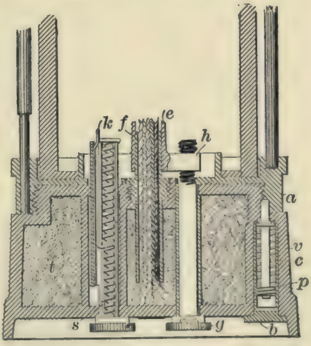
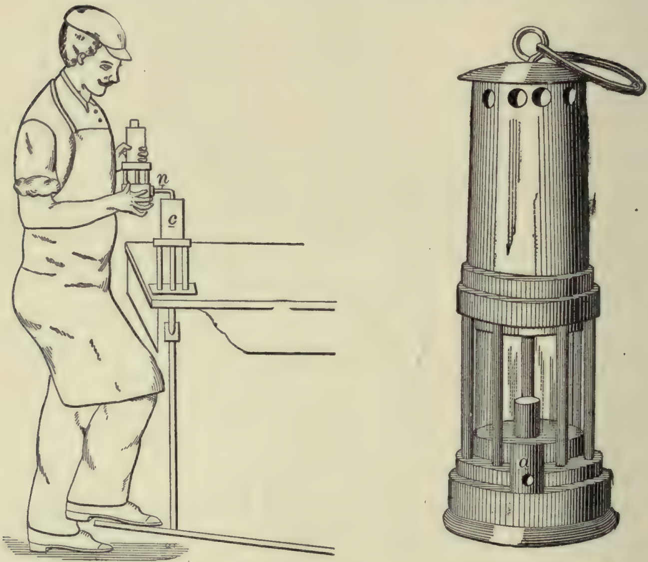


FIG. 54
A. S. L. Co. Magnet Lock

This lamp is constructed to burn benzine, the oil vessel being filled with cotton as in the Wolf lamp (Art. 175). The wick remains stationary in the tube *f*, while the flame of this lamp is regulated by raising or lowering the sheath *e* attached to this nut *h*, which is operated by the screw at the upper end of the shaft *g*. The igniter is shown on the left of the wick tube; it consists of a friction match slipped down between the spring *k* and the feed screw *s*, which is operated by a button underneath the oil vessel. On the upper end of the feed screw is a sharp-toothed wheel that strikes against the friction match and ignites it.



Opening the Lamp Cambrian Lamp

Fig. 55.—Showing Operation of the Air Lock

The **air lock** is a simple and efficient lock, consisting of a bolt held in place by a spring. The bolt fits tightly in a bore and is drawn back when desired by the vacuum created by a strong air pump in the lamp house. There is practically nothing in this lock that will easily get out of order, and in this respect it is superior to the magnet lock. The lock and its operation are shown in Fig. 55; *c* is the cylinder of the air pump, which is operated by a foot treadle, as shown. The nozzle *n* of the pump is forced into the hole *a* of the lamp, and the downward movement of the treadle creates a vacuum that draws back the bolt and allows the lamp to be unscrewed

PHOTOMETRY OF SAFETY LAMPS

179. Whatever contributes to increase or decrease the illuminating power of the safety lamp may be considered under the general head of the *photometry* of the lamp. Many factors that modify the illuminating power of lamps have been considered in connection with the details of lamp construction in studying the different types of lamps. Some of the lesser details relating to wicks, wick tubes, prickers, or trimmers, etc., will be considered here. The illuminating power of a lamp, however, will depend chiefly on the photometric value of the illuminant, together with the manner in which it is burned. This portion of the subject will, therefore, include references to the *classification and structure of illuminating flames; measurement of light; nature of illuminants;* and *lamp details affecting the combustion and therefore the light.*

180. Classification of Illuminating Flames.—Flames used for illuminating purposes may be classified properly with respect to the combustible that feeds them, which may be solid, liquid, or gaseous; thus giving three kinds of illuminating flames. These are *candle flames, oil-fed flames* and *gas-fed flames.*

181. Nature and Persistence of Flames.—Since (Art. 121) flame, as here understood, is the luminous vapor or gas produced by the combustion of the illuminant, it appears there are in all candle flames three operations necessary to produce the flame, namely, the melting of the solid matter, the distillation of the resulting liquid to form gas, and the combustion of the gas attended with the phenomenon of *flame.* In all oil-fed flames the last two of these operations only are required to produce the flame; while all gas-fed flames evidently require but one operation, the combustion of the gas. These differences play an important part with respect to the persistence of the flame or its resistance to extinction, and affect also, in some instances, the illuminating power of the flame. For example, in a candle flame the melted wax reaches the flame at a higher temperature than the oil of an oil-fed flame, and the gas is more readily distilled to feed the flame. As a consequence the candle flame is less easily extinguished than an oil-fed flame, provided the melted wax is not chilled by a cold draft of air. Again, all wick-fed flames, whether candle or oil flames, are less susceptible to extinction than gas-fed flames, for the reason that the gas being distilled in the flame, they are not dependent on an uninterrupted flow of gas through a tube, which may be momentarily cut off by a fluctuation of the air. Also, the gas distilled in a wick-fed flame has a higher temperature than the gas fed to a flame through a jet, making the flame not only more persistent, but improving its illuminating power.

182. Causes Producing Extinction of Flames.—The extinction of a lamp flame may be due to any one of the following causes: (1) an interruption of the feed; (2) the dilution of the air about the flame with extinctive gases, or, what is practically the same thing, the depletion of the oxygen of the air, or an insufficient supply of air to support the combustion of the flame; (3) the dispersion of the burning gas or vapor forming the flame, caused by a strong current of air, as when a flame is blown out by a puff of wind.

The *appearance of the flame* in each of these cases is more or less modified by the surrounding conditions. An interruption of the feed causes a diminution of the flame followed by its extinction if continued a sufficient length of time. An insufficient supply of oxygen or the presence of a sufficient proportion of extinctive gas produces the same result. A disturbance of the air about the flame, produced by a strong draft or current of air, causes a like disturbance of the flame, which is plainly manifest.

Briefly stated the extinction of a lamp flame is directly due to an interruption of the flow of the combustible to the flame, or to such a depletion of the oxygen of the air supporting the flame, or dilution of the atmosphere about the flame with extinctive gases as to separate too widely the individual centers of combustion. The heat produced is then insufficient to maintain the required temperature of the gases, and as a result the flame dies away, the direct cause being the absorption of heat by the large proportion of incombustible gases present in the air. What is true of the entire flame is likewise true, but in less degree, of a portion, particularly the outer portion, or the surface of the flame. The character of the atmosphere surrounding the flame, its composition and temperature, affect the combustion and appreciably alter the luminosity of the flame. It is this fact that causes such differences in the illuminating powers of some safety lamps, the reason for which is sometimes not readily apparent.

183. Standard Flame or Light Unit.—The unit adopted for the measurement of light is the intensity of the light produced by the burning of a properly trimmed sperm candle (6's) weighing six candles to the pound, and so proportioned that its flame, in a quiet atmosphere, will consume exactly 120 grains of spermaceti per hour, the intensity of the light at a unit's distance from its source being the *unit of measure.* Such a candle is often called *a standard candle*, and the intensity of its light *a candle power.*

Candles are made from different materials derived from the vegetable, animal, and mineral kingdoms, among which are tallow, wax, paraffin, spermaceti, and other products less familiar. The candles made by different makers from the same raw materials possess varying candle powers, according to the method employed to purify the material. However, calling the candle power of a standard sperm candle unity or 1, the relative values for other candles may be taken roughly as follows:

Paraffin.	.76	Wax.	.92
Stearin.	.77	Spermaceti.	1.00
Tallow.	.83	Paraffin, extra refined.	1.14

Some composite miner's candles exceed the illuminating power of the standard sperm candle, but these do not burn with uniform intensity as does the sperm candle.

184. The Photometer.—A variety of forms of apparatus have been devised for measuring the relative intensities of different sources of light by Rumford, Bunsen, Wheatstone, and others, but that of Bunsen perhaps combines the greatest degree of simplicity and accuracy for common use.

The general arrangement of the Bunsen photometer is shown in Fig. 56, where the lamp or other light to be tested is fixed at *A*, while the standard candle is stationary at *B*. A paper screen *s* is mounted on a suitable standard *h*, which can be moved along a graduated bar in line with the two lights. The index or arrow at the foot of the standard indicates the position of the screen on the bar, which is so graduated that when the screen is equally illuminated on both sides by the lights at *A* and *B* the reading shows the candle power of the light at *A* in terms of the standard candle at *B*.

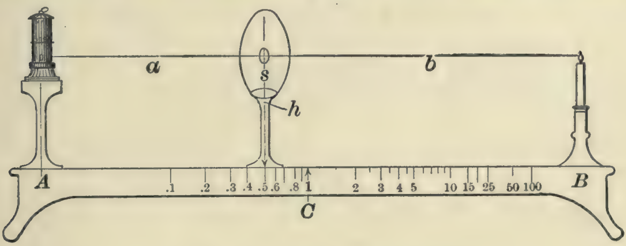


FIG. 56.—Bunsen's Photometer

In order to determine more readily the equality of the illumination on the opposite sides of the screen, a small spot the size of a silver dollar is made translucent with a little melted wax or paraffin. When the illumination from behind is less than that in front, the center appears as a dark spot that gradually vanishes as the screen is pushed nearer the light in the rear. At times there will be a slight difference when the screen is viewed from opposite sides and the mean of the two readings must be taken.

It is evident that when the screen is equally illumined on both sides, in a position *C* midway between the two lights, the intensities of the lights are equal or the candle power of the light *A* is 1. Now, to determine the illuminating power of a light referred to that of a standard candle as unity, or the candle power x of any light, use is made of the principle that *the illumination is directly proportional to the candle power of the light and inversely as the square of the distance from the source.* Calling the candle power of the light at A, x, and its distance from the screen a, the illumination of the side of the screen toward this light is $\frac{x}{a^2}$. In like manner the illumination of the screen due to the standard candle at a distance b is $\frac{1}{b^2}$. For the equal illumination of both sides of the screen $\frac{x}{a^2}=\frac{1}{b^2}$, and

$$x=\left(\frac{a}{b}\right)^2. \quad \ldots \ldots \quad (30)$$

By the above formula the graduation of the scale of the photometer can be calculated from .1 to 100 candle power.

185. Illuminants for Safety Lamps.—The only class of illuminants that can be considered at present as adapted for use in safety lamps are the oils, and from these should be excluded those highly volatile petroleum spirits having low flashing points that render them dangerous fluids to have in or about the mine and the buildings forming the surface plant.

Safety lamps have been designed to burn **solid paraffin** very much as the solid wax or tallow is consumed in the burning of a candle, but the restricted circulation of the lamp so far reduced the activity of the combustion that heat was lacking to melt the solid ingredients, and this form of illuminant was reluctantly abandoned.

Attempts have been made to use **acetylene gas** in mine lamps for the purpose of illumination, the lamp being arranged to generate its own gas by the contact of water with a carbide, generally barium carbide. The gas is supposed to be generated only as fast as it is consumed, this being accomplished by the automatic regulation of the flow of water into the carbide chamber. In a mine lamp designed by Mr. T. N. Thompson, Scranton, Pa., the acetylene vessel was arranged to be used interchangeably with a common oil vessel in the same lamp, as desired. The acetylene vessel consisted of two separate shallow cups or vessels, one above the other, the two being connected by a small brass tube. The upper vessel contained the water and the lower one the carbide, which rested on a perforated false bottom, beneath which gas might accumulate in small quantity. In this lamp the flow of water into the carbide chamber was intended to be regulated automatically by the pressure of the gas. When the gas was generated faster than it was consumed, the pressure rose and shut off the flow of water; and when the pressure fell more water was admitted. The gas was burned at a fine jet, and produced a beautiful flame and a very steady light of about 20 candle-power. The flame is not easily extinguished, but the carbide is expensive and the gas dangerous, and should never be used in a mine of any description, much less a gaseous mine requiring the use of safety lamps.

The *oils* used as illuminants in safety lamps are derived from vegetable, animal, and mineral sources.

The principal **vegetable oils** are *rape* and *colza;* these are derived from the seed of a special variety of turnip, which is largely cultivated for the purpose in Europe, and are practically the same oil, the former being the *winter rape,* while colza is the *summer rape.* The vegetable oils have a tendency to incrust the wick in burning, and therefore require more frequent snuffing to maintain a uniform standard of light. To avoid or lessen this difficulty it is customary to mix these oils with a proportion of petroleum (coal oil), the proportion varying from one-third part petroleum and one part rape or colza, to equal parts of both. The addition of the petroleum generally increases the illuminating power of the oil but creates a tendency of the flame to smoke, which limits the proportion of petroleum that can be added. These oils after being pressed out of the rape-seed are purified by treatment with sulphuric acid, which burns out the organic impurities of the oil, the latter being then washed to remove the refuse and the surplus acid.

The **animal oils** in common use are *lard oil* extracted from the lard obtained by refining the fat of hogs; *sperm oil* derived from the fat and the brain of the sperm whale; *whale oil* derived from the blubber of whales; and *seal oil* derived from the seal. All but the first of these are often called *fish oils.* Sperm and lard oils are very largely used in safety lamps, both pure and mixed with petroleum, as described above in reference to vegetable oils; seal, except highly refined qualities, and whale oils possess a greater tendency to smoke, for which reason they do not make a good oil for the safety lamp. Most of the sperm and lard oils sold for illuminating purposes have a greater or less proportion of the cheaper petroleum spirits mixed with them, and it is difficult to obtain always a reliable grade of illuminating oil. One of the advantages of using sperm or lard oil is the greater freedom from the incrusting of the wick. Trouble of this kind in the use of these oils will very largely determine the lack of purity of the oil. The illuminating power of sperm or lard oil will generally be found somewhat greater than that of vegetable oils, but much will here depend on the relative purity of the oils. A fairly pure vegetable oil may have a much superior illuminating power than a comparatively impure sperm or lard oil.

The **mineral oils** are all included under the general term *petroleum.* The crude oil is derived from certain oil-bearing strata, chiefly shales, sandstones, and limestones, by boring. The formation of petroleum is closely associated with that of coal; it is generally believed to be of organic origin, and to have been the result of the decomposition of vegetable and animal remains away from air, or to have been distilled from coal or other bituminous matters at a high temperature. It is often called *rock oil*, because it exudes from the strata. It is composed of hydrogen and carbon, and when the crude oil is heated there are distilled in order certain vaporous hydrocarbons, which condense on cooling and form oils of different degrees of inflammability; those distilling below 300° F. are generally termed *light* or *highly volatile* oils, while the products distilled between 300° and 570° F. form the common burning oil known as *kerosene* or *coal oil.* That distilled above 570° F. when condensed forms the heavy lubricating oils, and contains *paraffin,* which solidifies at 130° F. and is separated from the remaining heavy oil. Of the light oils, *gasoline* is distilled below 140° F.; *naphtha* or *benzoline* from 140° to 230° F.; and *benzine* from 230° to 300° F. The various products of this distillation are often spoken of as *refined petroleum.* About 1870 one of these light and highly inflammable oils, probably gasoline, was introduced into mining practice under the name *colzaline,* which has misled many to believe that this oil was a safe burning oil. Colzaline was first used in the Davy and Stephenson lamps, fitted with a special oil vessel (Fig. 52); the lamps being styled "protector lamps." Since then other lamps have been designed for burning naphtha, benzine, and similar highly volatile and dangerous oils, but their use is deprecated. When such oils or spirits are used a specially prepared filling cotton is first placed in the vessel of the lamp to absorb the fluid, and all excess of fluid is drained from the vessel before it is closed.

186. Flashing Point of Oils.—The temperature at which an oil gives off inflammable vapor that will ignite when a flame is held near the surface of the oil is called the *flashing point* of that oil. The comparative danger in the use of different highly volatile oils is determined by their flashing points, which should always be carefully ascertained for each new supply of such oil to avoid mistakes that may happen and to guard against adulteration with the lighter oils. All vegetable and animal oils have flashing points so high as to render them safe for all ordinary use in mine practice, but mineral oils have much lower flashing points and their use always requires caution in proportion as the oil is more volatile. When kerosene or coal oil is used to adulterate a vegetable or animal oil, its flashing point should not be lower than 80° F.

For all practical purposes the flashing point of an oil may be determined by what is called the *open test,* in which a small test tube is filled half full with the fluid to be tested and inserted in a bed of sand contained in a suitable pan or dish that may then be gradually heated by a lamp flame or gas burner. The temperature of the oil is determined with a thermometer inserted in the liquid, and at intervals the flashing of the vapor is tested by a flame applied to the mouth of the tube. A few trials will determine with sufficient accuracy the lowest temperature at which the vapor rising from the oil will flash. In testing oils with low flashing points a water bath may be substituted for the sand bath.

187. Comparison of Oils and Candles.—The photometric value and rate of burning of different oils and different makes and sizes of candles has been closely investigated by Mr. A. H. Stokes, in a large number of carefully conducted experiments, which show wide variations owing not only to differences in composition but to the conditions of burning the illuminant and particularly the form of lamp in which the oils were burned. So slight is the difference in the photometric values of the illuminants themselves and so vastly more potent the conditions affecting the combustion that it is quite evident that only in respect to a few particulars can a just comparison be made of these illuminants, and reliable data given concerning them.

In respect to candles, it is shown by the experiments that the composite wax candles having plaited wicks, to reduce the amount of snuffing necessary, do not have the candle power of a properly snuffed tallow candle, which in a few instances was practically double that of the standard sperm candle. The sperm candle, however, is the selected standard of light, because the illuminant is simple while the others are more complex. *The weight of material burned per unit of time determines the intensity of the light.* The wax composite candles tested burned on the average 145 grains of wax per hour, with an average yield of 1.44 candle power. The tallow candles burned an average of 190 grains of tallow per hour, with an average yield of 1.64 candle power. Practically the wax candles are more serviceable, because they require less attention than the tallow.

In respect to oils, a restricted circulation of air in the lamp has less effect to reduce the illumination when burning either vegetable or animal oil than when mineral oil is used, the latter requiring a larger supply of oxygen for their proper consumption than the former. When colza oil was burned in a single-gauze lamp the candle power was .57, which was reduced in a double-gauze Marsaut lamp to .52, or say 9 per cent. When a mixture of colza and petroleum was burned in the same lamps the reduction in candle power was from .84 to .72, or say 14 per cent. When petroleum was burned alone in the same lamps the reduction in candle power was from .96 to .63, or say 33 per cent. Thus, the effect of mixing petroleum in proper proportion with vegetable or animal oil is to reduce the incrusting of the wick, and increase the illumination, but these results are less pronounced in a closely bonneted lamp. In general, it may be stated that the addition of a lighter oil to vegetable or animal oil will increase the rate of burning. For example, rape oil was consumed in a double-gauze Marsaut lamp at the rate of 55 grains per hour, or 2 fluid ounces in 17 hr. 35 min. A mixture containing three parts rape and one part petroleum was consumed in the same lamp at the rate of 72 grains per hour, while a mixture of two parts rape and one part petroleum was burned at the rate of 77 grains per hour.

The attention given the matter of illuminants for safety lamps by the Royal Accidents in Mines Commission in England is worthy of the highest commendation; and their conclusions, based on an extensive series of experiments, are practical and safe. The findings of the commission in regard to the nature and the adaptation of different illuminants to mining conditions are in full accord with what has been already stated. The experiments of the commission were conducted with particular regard to the *adverse* conditions in gaseous and dusty mines, and the results obtained led the commission to unhesitatingly deplore the use in these mines of "petroleum or paraffin oils of such flashing points as might warrant their use, under *normal* conditions, as safe illuminants for miners' lamps." It is the adverse conditions that make the presence of a highly volatile oil in a safety lamp objectionable and dangerous. The danger is also greatly increased by the presence of an igniter (Art 175). The volatile spirit vaporizing from the wick of an extinguished lamp creates in a brief period of time an explosive atmosphere within the lamp, which causes a flash when the lamp is relighted with the igniter. This flashing of the lamp is dangerous in proportion to the condition of the gauze with respect to dust and the gaseous condition of the mine air. The relighting of an extinguished lamp always assumes a risk that should only be taken when the alternative presents an equal or even greater danger.

The results of the experiments of the commission referred to above may be briefly summarized as follows: (1) Refined rape oil of good quality maintains, for a brief period only, uniformity in the height of the flame and intensity of illumination, but the wick chars quickly and must be trimmed often. (2) Good clear seal oil is much superior to the refined vegetable oils, rape and colza, with respect to the maintenance of a fairly uniform height of flame and candle power without recourse to trimming the wick. In one experiment, using a two-gauze Marsaut lamp burning a good quality of seal oil in a still atmosphere, the lamp flame being left untouched, the height of the flame continued constant for two hours after lighting, and fell from 1 inch to .7 inch during a further period of five hours following. (3) Refined vegetable oil mixed with petroleum having a flashing point of 80° F., in the proportion of two volumes of the former to one volume of the latter, showed an improvement in the maintenance of a uniform height of flame, with practically the same candle power as the unadulterated vegetable oil. When the mixture, however, contained equal volumes of the vegetable oil and petroleum there was a further improvement in the maintenance of the flame and an increase of candle power. The same results were obtained by the addition of petroleum to seal oil. In each case the adulteration caused a considerable increase in the rapidity of consumption of oil and wick; the lamp became hotter and the wick took fire at the slot in the wick tube where the pricker is inserted to raise the wick.

The commission arrived at the following conclusions as a result of these experiments: A seal oil of good average quality is decidedly superior in general burning qualities, namely, the duration of uniformity in the height of flame, to the refined vegetable oils, rape and colza. The admixture to either of these oils, but especially to seal oil, of petroleum having a flashing point not lower than 80° F., in the proportion of *not more than* one volume of petroleum to two volumes of vegetable or animal oil, produces an illuminant considerably superior to either of the unadulterated vegetable or animal oils. Further, the experiments afforded no evidence that when petroleum and other oils were so mixed they were consumed in unequal proportions at any time during the burning of the lamp. What is said of seal oil in the report of the commission is likewise true to an even greater extent of the best grades of sperm and lard oil. For mine use it is important to secure the pure unadulterated sperm or lard oil, and make the addition of the kerosene or coal oil having a flashing point not less than 80° F., at the mine, in the proportion of one volume of coal oil to two volumes of the animal oil.

188. The Smoke Test.—The burning of a poor grade of oil in the lamps in a mine is not only unhealthy and in some cases unsafe, but often an intolerable nuisance. In general it is easy to detect on a single visit to a mine the burning of an inferior grade of oil by the peculiar oily soot deposited in the nostrils and on the skin. On quickly learns to discriminate between the oily filth of an impure illuminant and the legitimate dirt of a coal mine, when his attention has once been drawn to the matter. In some districts the miners have a bad habit of burning a considerable proportion of the heavy lubricating oil used on the mine cars, in their open lamps, and it is often quite impossible to stop the practice. Some drivers will often burn nothing but coal oil in their lamps. They do this because the flame of coal oil is not so readily blown out, and a driver never wants to "get in the dark."

Many of the oils offered on the market and sold as mine illuminating oils are wholly unfit for the purpose. The opinion, in some cases an honest one, is often expressed that an oil that is too poor for other use will still make a fair oil for mine lamps. It is sometimes a revelation to men to be told that the *best* grade of oil is required for a mine illuminant. So great has been the annoyance not to say danger growing out of the adulteration of mine oils that State departments have been forced to adopt measures to protect the health of mine workers. For practical purposes, it has been found that the chemical analysis of an oil to determine its degree of purity was too elaborate for general use and a more ready means had to be sought that could be employed at the mine and that would demonstrate in a practical manner the relative merits of oils with respect to the contamination of the mine air. Naturally, recourse was had to what has become known as *the smoke test*, and for the purpose of making this test, the apparatus shown in Fig. 57 has been used in Ohio and elsewhere. This consists of a rough wooden box about 2 feet long, 1 foot high, and from 6 to 8 inches deep. As shown in the figure, it is divided into four compartments, although a larger box can be used giving a greater number of divisions. In the center, above each compartment, holes $1\frac{1}{2}$ inches in diameter are bored, and into each hole is fitted a piece of tin rolled in the shape of a funnel to serve as a mantle or hood for collecting the smoke of the lamp placed beneath the funnel in each compartment. The smoke produced by the lamps is thus directed upwards into the tall glass chimneys placed loosely above each hole.

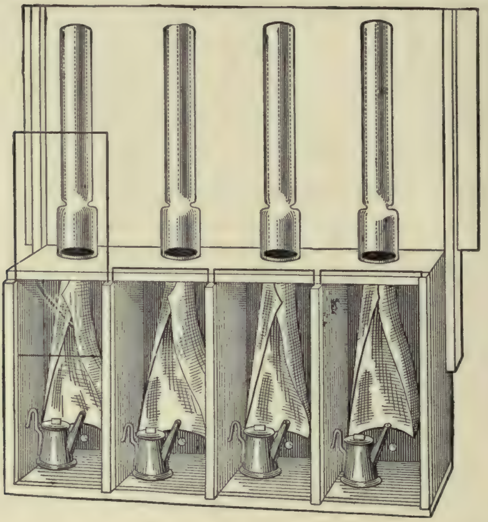


FIG. 57.—A Practical Smoke Test for Illuminating Oils

The quantity of smoke produced by each sample of oil burned is closely observed against the white screen placed behind the chimneys; this quantity is gauged roughly by the eye. One of the lamps is always filled with pure oil whose standard has been previously determined, and by comparison with this the relative purity of the other oils is judged. If the difference observed in any case is small, the glass door covering the front of the compartment should be slid down to reduce the volume of air, which then enters the box through the $\frac{3}{4}$-inch hole at the back of the box. In making this test it is necessary to use the same kind of lamp in each compartment; each lamp having the wick prepared with the same number of strands and in the same manner, to obtain uniformity of conditions. A new wick should be used in every case, and the lamp should be burned a sufficient length of time to burn off the top wicking and insure uniformity in this respect, before being placed in the box.

189. Wicks and Wick Tubes for Safety Lamps.—The two general forms of lamp wicks used in safety lamps are the round and the flat wicks; the circular or argand type of wick has been employed but to a limited extent only The round wick is generally the favorite, especially in lamps designed for testing for gas, because this form gives greater constancy of flame and more uniform conditions with respect to the burning of the wick. A flat wick is prone to cause a lack of uniformity in combustion throughout the flame; the center of the wick often consumes more rapidly than the corners, which are charred, causing a tendency to flaring and a smoky condition in the edges of the flame. The round wick produces a cone of flame in which the condition is everywhere uniform.

The wick of a lamp is, so to speak, the conveyancer of the oil to the flame, the flow of the oil being induced by the capillarity of the wick. Flat wicks are loosely woven or plaited, the warp forming the chief strands of the wick, while the woof or cross thread by which they are sewed together is a fine thread that will not interfere with the upward flow of the oil. Round wicks are generally made up from ball wickings; the threads forming the strand of the ball being simply laid parallel, five or six threads forming the strand. A length of about 2 feet is cut from the ball and folded to make a wick of, say five strands about 5 inches in length. This is bound at the end by one or two threads drawn from the wick; the ends of these threads are easily blown through the wick tube and serve to draw the wick into the tube, after which they are burned off. The wick must fit loosely in the tube; if too tight, a few threads should be carefully drawn out of the wick, taking care not to tangle the other threads. A flat wick is generally made a very little broader than the tube; the wick is $\frac{1}{2}$ inch wide and the top of the tube $\frac{7}{16}$ inch. This tube should always be made corrugated on one side, to provide for the free circulation of the oil in the wick. Most flat wick tubes have a small air tube soldered on one side to give, as it is claimed, vent to the air in the oil vessel.

Lamp wicks should never be used when they have become gummed or clogged with old oil, as the lamp will then fail to burn properly. A short wick frequently renewed will be the means of greatly improving the light. The flame in a safety lamp should be set high enough in the lamp to reduce to a minimum the shadow thrown on the ground by the lamp. The top of the wick tube should not be less than $\frac{1}{2}$ inch above the bottom of the glass.

The **pricker** of a safety lamp is an important item. The usual form in use is the small upright rod extending through the oil vessel. This pricker affords no adequate means of properly cleansing the wick from the crusts of carbonized material that form on the wick. The incrusting of the wick is due largely to impurities in the oil; it is also increased by incomplete combustion, which may be due to a variety of causes connected with the construction of the lamp, and even the condition of the mine air. Some men become quite expert in cleaning the wick with the pricker and others are almost certain to lose their light in the attempt to improve its condition. If all that were required were the raising and lowering of the wick, other arrangements could easily be introduced that would perform that work more easily and perfectly than the pricker, but the wick must be cleaned as well as moved up and down, and the pricker is thus far the only device offered that will do this, however imperfectly.

190. Illuminating Power of Different Safety Lamps.—Aside from the photometric value of the illuminant burned in the lamp, every lamp has an illuminating power peculiar to its construction. In lamps in which the flame is surrounded by wire gauze, as in the Davy lamp, the illuminating power is much reduced, because the light is cut off by the wires of the gauze. In lamps of the Clanny type where the flame is surrounded by a glass chimney, the illuminating power is greatly improved but still impaired by other features of lamp construction that affect the circulation of the air entering and passing through the lamp and particularly the supply of oxygen to the flame. In some lamps, by virtue of the interior arrangement or the restriction of the discharge at the top of the lamp or both of these combined, much of the vitiated air in the upper part of the lamp finds its way into the combustion chamber. This dilution of the air in the combustion chamber by the extinctive gases from the top of the lamp impairs the combustion of the oil and reduces the luminosity of the flame. The reason of the comparatively low candle power of the Mueseler lamp is probably that much of the air after passing over the flame fails to pass up the central chimney directly as it should, and is wafted back into the combustion chamber, thus diluting the entering air, or blocking the intake through which it attempts to pass. In either case the energy of the combustion in the flame is impaired from a lack of oxygen.

TABLE 24

AVERAGE ILLUMINATING POWER OF DIFFERENT SAFETY LAMPS

Lamp	Candle Power
Davy (common)	.15
Davy (Jack)	.08
Davy (in case)	.16
Stephenson, "Geordie"	.10
Clanny (improved), various types	.25 to .50
Evan Thomas, No. 7	.40
Marsaut (two-gauze)	.60
Marsaut (three-gauze)	.45
Gray	.33
Ashworth, No. 4	.55
Ashworth-Hepplewhite-Gray	.65
Ashworth-Hepplewhite-Gray (recent)	.79
Beard, Eloin-Marsaut (two-gauze) sperm oil	.75
Beard, Eloin-Marsaut (three-gauze), sperm oil.	.60
Mueseler (Belgian)	.35, reduces gradually
Mueseler (English)	.30
Wolf, naphtha (benzine); when first lighted	1.00
" " " at end of shift	.80

From the above facts it is readily observed that any one type of lamp may show a wide variation in candle power, according to the quality and kind of illuminating oil burned and certain slight modifications in construction, which affect the combustion. For example, the different types of Davy lamps, examined by the British Accidents in Mines Commission, burning different oils gave values ranging from .07 to .22 candle power, while a fair average value for the common Davy lamp is between .15 and .16 candle power. Table 24 gives the average candle power of the different types of lamps burning a good quality of vegetable oil, except where another illuminant is specified.

CHAPTER VII

TESTING FOR GAS

GAS INDICATORS

191. Under this heading are included all such means and appliances as may be used to determine the percentage of marsh gas (methane) present in the air, other than the ordinary flame test by which the percentage of gas is estimated from the height of the flame cap visible above the lamp flame.

192. Monnier, Coquillion, Maurice. — A number of ingenious devices have been tried at different times having for their purpose the indication of the presence of gas in mine air, but with few exceptions all have proved impracticable for common use in the mine. Monnier, Coquillion, and Maurice each constructed indicators for determining the relative volume of inflammable gas in samples of air tested. These devices all depended on burning out the gas from a carefully measured volume of gas and air, and afterwards measuring the remaining volume of air and carbon dioxide at the same temperature and pressure. In each case the combustion was effected by means of a fine platinum wire fused into a glass tube that could be filled with the air to be tested. Having noted the temperature and pressure of the contained air by a suitably arranged thermometer, and barometer or pressure gauge, the platinum wire was brought to a white heat for a few seconds by passing through it a current from a battery or a magneto-electric machine, thereby consuming the inflammable gas and producing in its place carbon dioxide and water vapor, which vapor was condensed when the temperature again became normal. A comparison of the resulting volume of the residuum air with the results of previous experiments when the proportion of gas in the air was known gave the percentage of gas present in the sample of air tested.

193. Aitken.—A similar device constructed by Mr. John Aitken (1880) determined the percentage of gas present from the decrease of pressure caused by the consumption of the gas.

194. Ansell, Libin.—The indicators of MM. Ansell (1865) and Libin (1883) depended on the principle of the diffusion of gases. In these devices two closed spaces of equal volume, the one filled with air and the other with air and gas at equal temperature and pressure, were separated by a thin porous partition. As diffusion proceeded the pressure in the space filled with pure air increased till it attained a maximum and then gradually declined till the original pressure was reached; the maximum increase of pressure has been found to be nearly proportional to the percentage of gas present in the air tested.

195. Aitken, Smith.—Another class of indicators constructed by Aitken and Smith, respectively, depended on the heating effect of the gas. Mr. Aitken in the construction of his second indicator employed two thermometers, which he placed side by side in a tube arranged so that the air to be tested could be drawn through the tube. The bulb of one of the thermometers was coated with a thin covering of a mixture of plaster of Paris and platinum black, which induced chemical action and caused the combustion of the gas. The heat due to the combustion raised the temperature and caused the thermometer having its bulb coated to give a higher reading than the other thermometer. The difference between the readings of the two thermometers was assumed to be a fair index of the percentage of gas present in the air tested. Other causes, however, might operate to increase or decrease this difference, which would render the indications unreliable. It was further found necessary in order to determine small percentages of gas with this indicator to raise the temperature of the air being tested to that of boiling water, which made the device of no practical value in the mines.

The indicator constructed by Dr. Angus Smith was also of no practical value. It consisted of a strong glass tube closed at one end and fitted with an air-tight piston. When the tube was filled with air containing not less than 5 per cent. of gas and the piston was pushed down quickly, sufficient heat would be generated by the compression of the air to fire the gas and cause a flash. When less than this percentage of gas was present, however, it was found necessary to place a small quantity of platinum black in the bottom of the tube to cause the ignition of the gas, but even then no flash was obtained when less than 2.5 per cent. of gas was present. This percentage of gas was more easily found by means of the ordinary flame test, however, and in less time.

196. The Liveing Indicator.—The indicator designed by Mr. E. H. T. Liveing proved of greater practical value and has been used to a considerable extent in mines. Like the Aitken and Smith indicators just described, it depended on the heating effect of the gas present in the air being tested, but the intensity of this effect was measured by the relative brilliancy of two platinum wires of equal electrical resistance and heated to incandescence by an electrical current. The apparatus, except the lower portion of the box, which contained the magneto-electric machine for generating the current, is shown in section in Fig. 58. It consisted of two platinum coils, one of which *m* was inclosed in a sealed tube *a* containing pure air while the other *n* was contained in a similar tube *b*, provided with gauze-protected openings for the admission of the gas-laden air to be tested. These small tubes *a* and *b* were placed opposite each other in a larger tube *H*, a portion of which was cut away from *c* to *d* to permit of the movement of the sliding section *T* carrying the screen *s*. This telescopic sliding section *T* of the tube was provided with a glass window *w* for making observations. The ends of the two small tubes *a* and *b* facing each other were closed with glass plates *g* that permitted the rays of light from the incandescent coils *m* and *n* to fall upon the two inclined faces of the wedge-shaped screen *s* between them. By applying the mouth to the mouthpiece *p* the air to be tested was drawn into the tube *H* through an opening *o*, filling the tube *b* having the openings covered with wire gauze. By turning a crank on the side of the box the magneto-electric machine was made to generate a current, which passed through the two coils *m* and *n*, heating them to the same intensity if the air in the box contained no gas. If gas was present, however, its com-

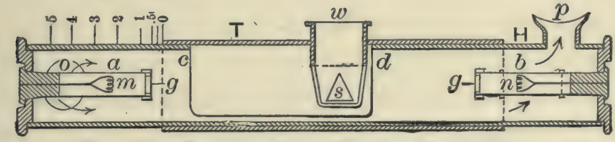


FIG. 58.—Section of the Liveing Gas Indicator

bustion in contact with the coil *n* increased the temperature and the brilliancy of the incandescent wire, and as a result the face of the screen *s* toward *n* was brighter than that toward *m*. The sliding tube *T* is now moved to the left till both these faces are equally illuminated, when the reading of the end of the sliding section on the graduated scale shown at the left indicates the percentage of gas present in the air tested. That this method affords an accurate means of determining very small percentages of gas, provided the observer is able to correctly judge of the equal illumination of the two faces of the screen, is shown by the following rapid increase of the illuminating power of the incandescent platinum coil: namely, pure air = 1; air containing gas: .25 per cent. 1.23; .50 per cent. 1.52; 1 per cent. 2.24; 1.5 per cent. 3.10; 2 per cent. 4.28; 2.5 per cent. 6.00; 3 per cent. 8.55; 3.5 per cent. 12.70; 4 per cent. 19.30; 4.5 per cent. 31.00; 5 per cent. 51.40.

There are some sources of error in the use of this machine, which at the first were unsuspected. The relative brilliancy of the two coils forms a true index of the degree of inflammability of the gas-laden air, but the inflammability increases from zero as the proportion of gas increases till the latter forms 9.46 per cent. of the mixture, when it reaches a maximum; beyond this point the inflammability of the mixture decreases as the percentage of gas increases (Art. 88). Owing to this fact, it is clear the indications of the machine represent, each, two conditions with respect to the proportion of gas in the air, and these conditions are far from being like dangerous. A lamp flame would reveal at once which of the two conditions was the one that existed in the air tested, because of the increasing extinctive effect of the higher percentages of the gas Again, it has been found that the electrical resistance of platinum wire on continued exposure to the action of gas changes so rapidly as to render the results quite uncertain after the first few tests made; besides there is always the imminent danger of the electrical apparatus causing the ignition of the gas from the sparking of the contacts. For these reasons the device is not all that is required of a gas indicator for mine use.

197. The Forbes Indicator.—Numerous other forms of indicators have been devised, some correct in principle but not of practical application to mine work, or too expensive, weighty, or cumbersome; while others consume too much time or require too careful manipulation to be of general use. The most ingenious of these perhaps was the indicator invented by Prof. George Forbes, which depended on the difference in the length of the sound waves in gases or air of different densities, as compared with that of the same note in pure air. In this device a tuning fork of 512 vibrations per second was sounded in the mouth of a brass tube 1 inch in diameter and about 6 inches long and fitted with a tight piston whose position in the tube was indicated by the index of a graduated disk 3 inches in diameter. The piston was first set so as to produce the greatest resonance when the fork was sounded and the tube filled with pure air. The tube was then filled with the air to be tested and the movement of the piston necessary to produce a maximum resonance indicates the percentage of gas present. The temperature at each observation was noted by the attached thermometer, and the necessary correction made for any change of density due to the temperature of the air.

198. The Garforth Appliance.—The device used by W. E. Garforth for collecting gas from cavities in the roof, where it would be difficult or inconvenient and perhaps unsafe to introduce a lamp, consisted of a simple hand bulb of india rubber provided with a long neck that could be inserted upwards through a tube extending completely through the oil vessel of a safety lamp, so as to discharge the contents of the bulb drawn from the roof into the combustion chamber of the lamp close to the lamp flame. This device could hardly be styled an indicator as it has been called. It embodies no new principle.

199. Other Devices.—Devices have been proposed by which a safety lamp was to be provided with some appliance, such as a double strip of two metals of unequal expansion, and that would by its movement ring a small bell attached to the lamp whenever the heat of the burning gas reached a certain point. Another arrangement closed certain air vents in the lamp, which was promptly extinguished whenever gas fired in the lamp. Other equally ingenious but unreliable devices have been proposed, but none of these have seemed to appeal to the practical mining man, and as a consequence have failed of general adoption.

200. Signal Apparatus.—Still another form of gas indicator is that designed to transmit a signal of warning to the superintendent's office, on the surface, when the presence of gas in sufficient quantity set the device in operation at different points in the mine where the indicators were placed. Several forms of such apparatus have been tried at different times and in different countries, only to receive the condemnation of practical men, for the excellent reason that all such indicators can only reveal the presence of gas at some isolated point, which under the ever-changing condition of the mine and the ventilating current is almost certain not to be the point of greatest danger. All the systems of this kind thus far proposed would at the best give a very tardy warning, and in every case the action has depended on some delicate means—for example, the ascensional force of the gas acting on a delicate balance located in a position near the roof—as in the apparatus proposed by the French engineer, Jean Molas. This was likewise the principle of action of the system devised by an American engineer, Mr. G. H. Carlton. To the same class belong the proposed methods of Messrs. George Duggan, Henry Reece, Chaloner, and Della Bella, all of whom presented their plans to the Royal Accidents Commission of England in 1880. Another plan likewise proposed by an American and possessing a greater element of danger consists in transmitting through the workings a current from a Ruhmkorff induction coil on the surface. The wiring was arranged with numerous breaks at different points in the mine where gas might accumulate, each being protected by a covering of wire gauze, which while it admitted the gas to the sparking wire was expected to prevent the ignition of the gas outside of the gauze. It is hard to understand how such a dangerous contrivance could have emanated from the brain of any practical man.

201. Shaw's Signaling System.—An equally impracticable though less dangerous plan was that proposed and brought prominently before the mining public in 1887 by Mr. Thomas M. Shaw, a mining engineer of Ohio. Mr. Shaw's experience in the determination and measurement of gases in the laboratory enabled him to devise an excellent machine for determining with great accuracy the percentage of certain gases when mixed with air. This machine afterward became known as the Shaw Gas Machine and will be described later. Mr. Shaw's scheme, however, to utilize this machine in connection with an elaborate system of pipes extending to different points in the mine for the purpose of drawing the gas from these points to the surface and passing it continuously through the machine to determine its percentage composition was highly impracticable for various reasons. As previously stated, such indications would be tardy and would only make known the gaseous condition of certain points that become, under the natural conditions in mines, more or less isolated from the points of greatest danger at the working face. To be of practical value a determination of gas must be made promptly and at the point of danger. The pipes leading to the several working places as proposed for the working out of this system were to be $\frac{1}{4}$ inch in diameter, and the claim that these would serve in a measure to drain the gas from the workings was of course absurd. A small pump was to be employed at the surface to draw the gas from the mine. The attempt to enforce the adoption of this system in the gaseous mines of Pennsylvania by legislative enactment was frustrated, largely through the efforts of Mr. Rufus J. Foster, mining engineer and editor of The Colliery Engineer, now Mines and Minerals, and serves as an illustration of one of the numerous dangers to which mining operations are constantly exposed from unwise legislation.

202. The Shaw Gas Machine.—This machine depends on the principle explained in Art. 88 with respect to the explosive limits of pure methane. The explosive limits of all inflammable gases are fixed, but this condition depends on the purity, and the density of the gas as influenced by pressure and temperature. The theoretical consideration of the principle involved in this machine would contemplate some points of which the machine takes no cognizance. For example, when calculating the percentage of any feeder gas that will render mine air explosive, there are two points at least that seriously embarrass such a theoretical calculation, but which do not interfere with the practical results obtained with the machine. Thus, the feeder gas is a mixture of different gases and its composition in most cases is unknown, while the mine air itself is contaminated with other gases, besides having lost some of its oxygen. A little reflection on the method in which the explosiveness of the mine air is determined in the use of the machine will make it clear that the question here is what proportion of the feeder gas added to the mine air with all its impurities will bring the mixture to the explosive point. This determination is not worked out, therefore, as a theoretical question, and the percentage obtained in any given case is not the percentage of *pure* gas mixed with *pure* air that is explosive, or even the percentage of feeder gas in pure air, but merely the percentage of *feeder* gas that will render the *mine* air explosive, contaminated as it is with other combustible gases, including fine dust in suspension and extinctive gases, and depleted in oxygen.

As shown in Fig. 59, the machine consists of two cylinders, *A* and *B*, having air-tight pistons attached to and operated by the strong lever arm *G*, which in turn is operated by the connecting rod *V* and an eccentric driven by the gears *P* and the crank *N*. The large air cylinder *A* is fixed, while the small gas cylinder *B* is made to slide along the graduated scale *S*. The graduations on the lower scale *S* correspond to those on the beam *G*, and both express in percentage the volume ratio of the two cylinders (piston displacement) for any position of the cylinder *B*. This cylinder is set by a small index mark on its side and clamped by the arm seen extending below the scale under the cylinder; the crosshead to which the piston rod *H* is attached is set to the corresponding graduation on the beam and fastened by the set screw *C*. The construction of the machine is such that gas may be mixed with air in any required proportion, and the percentage of gas in the mixture will be determined by the graduations to .1 per cent. By turning the crank *N* the pistons in both the air and gas cylinders are moved up and down together. Each cylinder is connected below by means of the rubber tube *M* and a pipe underneath the frame, to the distribution box *L*, which consists of two closely fitting disks, the lower one being fixed while the upper one is rotated to and fro by the rod *W* driven by the gear wheel *P*. Such is the arrangement of the valve ducts within the box *L* that at each stroke of the beam and pistons air and gas from a main or other supply are drawn into their respective cylinders, from which they are forced back through the distribution valve *L* and thence into the mixer *K*, whence they flow into the

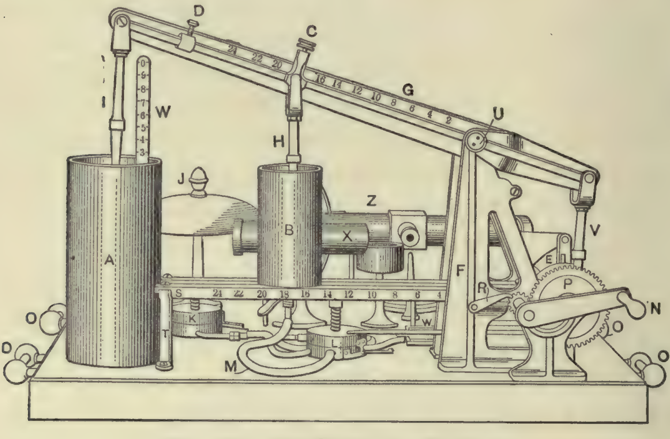


FIG. 59.—The Shaw Gas Machine

combustion chamber Z. This is a brass tube about 12 inches long and 1.5 inches in diameter, closed at one end and provided at the other with a movable piston so placed as to be driven forcibly against the gong J whenever an explosion occurs within the cylinder Z. In the operation of the machine the mixture of air and gas flowing from the mixer K fills the combustion tube Z and issues from the small orifice seen on the side about the center of the tube, this orifice being immediately above a gas jet that is burning and by which the mixture is ignited if it is inflammable. If the mixture is explosive its ignition at the orifice will cause the explosion, of the contents of the tube, which will be accompanied with the ringing of the gong as explained.

The method of determining the percentage of gas in a mixture of that gas and air is briefly as follows:

It must first be determined by trial what is the least proportion of the gas that will form an explosive mixture with pure air. To do this the tube shown on the right of the distribution box L is left open so that pure air will be drawn into the cylinder A when the pump is operated; the cylinder B is always connected through the box L to the gas main or other supply and therefore pumps gas. By a few trials the position of the cylinder B is soon found where the mixture in the combustion tube Z is feebly explosive. The readings of the graduated arm and scale, which must correspond, will show the percentage of gas in the mixture and make known the higher explosive limit of the gas (Table 12). This operation is called *standardizing the gas.*

Having found the percentage of this gas required to cause explosion, it is now possible to determine the percentage of the same gas in any mixture of the gas with air not exceeding the higher explosive limit of the gas. To do this the air to be tested is drawn into the air cylinder *A* through the tube shown on the right of the box *L* by connecting this tube with the bag containing the air or other source of supply. Instead of pure air cylinder *A* may now be pumping a small percentage of gas, which with the gas being pumped by cylinder *B* would cause a violent explosion in the combustion tube *Z*. To avoid such an explosion it is well to set the cylinder *B* back a little, and by trial the point is soon found where the mixture is feebly explosive as before. The amount the gas cylinder *B* has been moved back evidently shows the percentage of gas contained in the air tested. It is claimed that the graduations of the beam and scale have been made to read percentages, but it is evident that when the scale expresses correctly the percentage composition of the contents of the *two* cylinders it cannot at the same time express correctly the percentage of the gas contained in the air in the large cylinder alone. When the percentage marking the explosive limit is low, however, the results obtained are correct for all practical purposes in mine work. For example, suppose it is found on trial that a certain feeder gas in a mine begins to explode feebly when mixed with pure air in the proportion of 8 per cent. of gas and 92 per cent. of air. A mixture of this gas and air contained in a bag when tested required the gas cylinder to be set back to 6 per cent. to obtain a feeble explosion, thus showing $8-6=2$ per cent. of gas in the air tested. This is actually 2 per cent. of the mixture after the 6 per cent. of gas had been added, making 2 volumes of gas in the 94 volumes of test air, or $\frac{2}{94}\times 100=2.13$ per cent. nearly.

203. Use of the Shaw Gas Machine.—A difficulty would arise in the use of this machine if the air tested contained a greater percentage of gas than that marking the higher explosive limit. In this case, if the mixture is within the explosive range of the gas, a very violent explosion may be obtained or the explosion may be quite feeble, according to the near approach to the maximum explosive point or one of the explosive limits (Art. 88). The results obtained in such a case are at times very confusing, because if the mixture exploded in the combustion tube is between the lower explosive limit and the maximum explosive point, setting the gas cylinder back may increase the force of the explosion and setting the cylinder forward so as to increase the proportion of gas may actually cause the explosion to cease. The writer has had this occur a number of times when engaged in calibrating the sight indicator. There are different ways of determining the percentage of gas in such mixtures by changing the connections. Thus, working from the higher explosive limit of the gas as a standard: (1) Cylinder *A* drawing test air and cylinder *B* drawing gas, it is possible to determine any percentage of gas from zero to the higher explosive limit by moving the gas cylinder to any position between *standard* and *zero*. (2) Cylinder *A* drawing test air and cylinder *B* drawing pure air, it is possible to determine percentages of gas above the higher explosive limit by moving the gas cylinder forward to any position whatever on the scale. In this case, however, the percentages are not read from the scale, but must be calculated; this, indeed, is true also in case (1), but the error there in taking the scale readings as percentages is slight. (3) Cylinder *A* drawing pure air and cylinder *B* drawing test air, it is possible to determine high percentages of gas only, since in this arrangement the only gas pumped is but a fraction of the flow from the small cylinder and it is only when the percentage is high that this can reach explosive proportions in the combustion tube of the machine.

Letting J = the required percentage, S = the higher explosive limit found in standardizing the gas, and R = the reading of the scale, the following formulas represent respectively the three arrangements described above:

1. $$J=\left(\frac{S-R}{100-R}\right)100; \quad \ldots \ldots \quad (31)$$

2. $$J=\left(\frac{S}{100-R}\right)100; \quad \ldots \ldots \quad (32)$$

3. $$J=\frac{S}{R}100. \quad \ldots \ldots \quad (33)$$

It is apparent in the first case, formula 31, that R cannot exceed S in value, and when $R=S$ the percentage of gas is zero. In the third case, formula 33, R cannot be less than S in value, and when $R=S$ the percentage is 100. Again, in the second case, formula 32, giving R its greatest possible value, $R=25$ (see scale, Fig. 59), $J=\frac{4}{3}S$, which shows the highest percentage of gas that can be determined by this arrangement. In like manner the least possible percentage of gas that can be determined in the third case is found by making $R=25$ when $J=4S$. Comparing these two last cases it is apparent there is quite a gap between $\frac{4}{3}S$ and $4S$ that cannot be determined by any of these methods.

It is possible, though not as convenient, owing to the gas being sharper and the explosions more violent, to work from the lower explosive limit of the gas, standardizing by this limit instead of the higher limit as previously described. The same formulas will apply in the same manner as described above; but it is apparent that the value of S being increased it is possible to cover some of the gap not covered previously. Calling the standard corresponding to the higher explosive limit S_h and that of the lower limit S_l, the gap still remaining is from $\frac{4}{3}S_l$ to $4S_h$. It is not possible to determine percentages directly in this gap with the machine graduated only to 25 per cent., the relative volumes of the two cylinders remaining unchanged; the volume ratio of these cylinders is now $3:1 =$ air:gas. It is possible, however, to make such determinations indirectly; that is to say, by reducing or increasing the percentage of gas in the air to be tested, preferably the former. For example, suppose the air to be tested actually contains 25 per cent. of gas (methane). The values of the higher and lower explosive limits of methane (Table 12) are respectively $S_h = 7.14$ per cent. and $S_l = 16.67$ per cent.; hence $\frac{4}{3}S_l = 22.22$ per cent. and $4S_h = 28.56$ per cent., so that this mixture will not give results in any of the arrangements explained, whether standardized by the higher or the lower explosive limit. But, connecting the bag containing the air to be tested with the small gas cylinder, and setting this cylinder out to the end of the scale (25 per cent.) and operating the pump, a new mixture will be pumped containing 25 per cent. of the test air. In other words, the percentage of gas contained in this new mixture will be exactly one-fourth of the percentage in the original test air. This new mixture containing then 6.25 per cent. of gas can be caught in a bag attached at the mixer K, and can then be easily tested by the first method described, and the resulting percentage multiplied by 4 will give the true percentage of gas in the air.

The Shaw gas machine is a valuable machine, but is not adapted to underground work under any possible conditions because it is not portable, and by the time air is bagged and taken to the surface and the percentage of gas it contains determined, the condition in the mine may have wholly changed, becoming more dangerous or less so. Moreover, the air taken in the bags represents only a local condition, and does not therefore possess the general value that it should to assist the practical operation of the mine. Any determination of the percentage of gas in the air of mine workings must be made promptly at the point of suspected danger, in order that immediate remedial measures may be at once adopted.

204. The Beard-Mackie Sight Indicator.—This device is the joint invention of the author and Mr. Matthew D. Mackie, an experienced fire boss of the Marvine Colliery, Scranton, Pa. It was first introduced in mines in March, 1903. Fig. 60 shows the indicator detached from the lamp. It consists of "A ∩-shaped support made of No. 14 brass wire and riveted to a brass disk, which forms its base and fits over the wick tube of the lamp. The indicator is thus held firmly in position in the lamp by the same nipple that secures the burner. As shown in Fig. 60, supported on this frame are seven platinum cross wires—a straight standard wire at the bottom, and above this six percentage wires each having a small loop or circle in the middle. The loops enable the incandescent wires to be more readily and quickly discerned within the gauze of the lamp. The lower standard wire is for the purpose of gauging the height of the lamp flame in

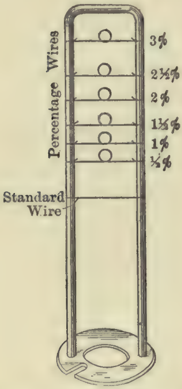


FIG. 60.—The Beard-Mackie Sight Indicator Detached from Lamp

pure air. The presence of gas is then made known by the incandescence of the successive percentage wires, the percentage of gas being indicated at once by the number of wires aglow. The successive percentage wires indicate respectively 0.5, 1, 1.5, 2, 2.5, and 3 per cent. of gas in the air. . . .

205. Principle of the Sight Indicator.—"The device depends upon the well-known property of platinum of inducing the union of oxygen and other gases in contact with its surface, which property is possessed by the compact metal to a less degree than spongy platinum only in proportion as its surface is less than the surface of the latter. The stimulation of the chemical activity at the surface of the metal when gas is present is sufficient to maintain a red heat in a platinum foil. This is shown by heating the foil to redness in a gas flame and then shutting off the gas suddenly and at once turning it on again. While the heat developed in this case is not sufficient to cause the gas to ignite, it maintains a red glow in the platinum, which only ceases when the gas is shut off. The degree of heating is determined by the ratio of the surface to the volume of the metal, which in the case of spongy platinum is sufficient to cause the ignition of the gas and which in the fine wires of the indicator causes a white heat that enables the lamp to hold its flame, relighting the lamp after extinction in 'sharp' gas. This feature, which is of great advantage in the work of testing for gas in the mine, has been often proved both in the mine and in the laboratory when the lamp has been introduced into an atmosphere of gas that was extinctive owing to the excess of gas. All flame would then die out within the lamp, the wires alone remaining incandescent and relighting the gas when the lamp is slowly withdrawn, the gas in turn relighting the lamp. It is noteworthy that the platinum wires incandesce at a considerable height above the tip of the flame, owing to the peculiar property of the platinum that stimulates the combustion of the gas in contact with its surface.

"The underlying principle of this device is practically the same as that involved in the Liveing indicator, . . . but in the Liveing indicator the original source of heat is an electric current made to pass through the platinum wire, while in the present device the heat is derived originally from the flame of the safety lamp in which the indicator is placed. . . .

206. Experiments Previous to Calibration.—"In the calibration of the indicator an unbonneted Davy lamp (Fig. 61) burning pure sperm oil was used. The lamp was hung in a small wooden box 10 in. by 10 in. by 16 in., shown in Fig. 62. This box was connected below and above with a 10-inch pipe that formed a stack for the escape of the gas. The box was provided with a glass door at the front, through which the behavior of the lamps could be distinctly observed; the pipe was open at the bottom and top to permit the free upward passage of the air and gas. City gas was used, and this was introduced into the lower end of the stack by the rubber tube leading from a gas jet above. A damper in the pipe just above the box allowed the operator to accumulate the gas so as to obtain any desired gaseous condition of the air passing through the box in a constant stream; and it was also possible to

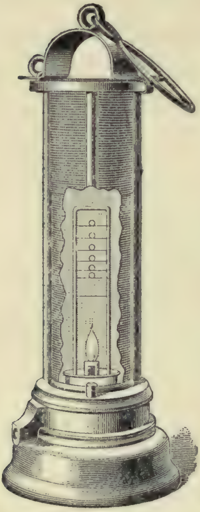


FIG. 61.—The Beard-Mackie Sight Indicator in Davy Lamp

maintain this constant condition of the passing current for any length of time, so as to enable a test to be made with the Shaw gas machine located at one side of the box. A rubber tube connected this machine with a short brass pipe inserted in the back of the box and extending to its center, terminating at a point close to the gauze where the feed air entered the lamp. By this means it was possible to obtain an accurate test of the air that was feeding the lamp, at any desired moment.

"Before placing an indicator in the lamp, experiments were made to ascertain the relation between the heights of the flame cap and the percentages of gas causing the same, for the purpose of confirming the law formulated by Mr. William Galloway, which says that the height of the cap varies with the cube of the percentage of gas present in the air. The height (h) in inches for the percentage (J) was thus found to be expressed by the formulas

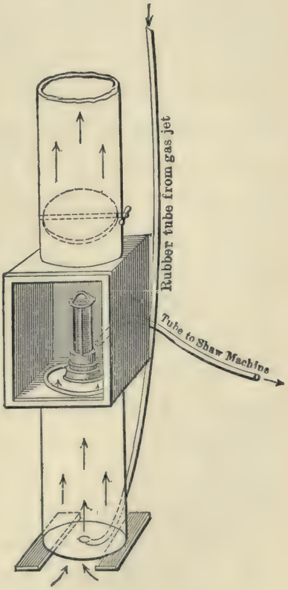


FIG. 62.—Test Chamber Used in Calibrating the Beard-Mackie Sight Indicator

Unbonneted Davy (sperm oil), $J = \sqrt[3]{36h}$ (Beard); (34)

Bonneted Davy (sperm oil), $J = \sqrt[3]{70h}$ (Galloway). (35)

207. Calibration of the Sight Indicator.—"Having made these preliminary tests, an indicator frame, with cross wires of platinum arranged upon it at uniform distances apart, was placed in the lamp, and careful observations made to ascertain the relation of the height of incandescence of these wires to the percentage of gas in the air passing upwards through the box. By this means the heights of the several percentage wires were determined. These observations and experiments, repeated many times and in different ways, revealed the discouraging fact that it was seemingly impracticable to attempt to insert a 0.5-per cent. wire, because its position was too close to the standard wire used to gauge the flame. So close would this first percentage wire be to the standard wire that it required considerable care to set the flame so that it would incandesce the latter without causing both to glow. This difficulty, however, was successfully overcome later by using a slightly heavier iron wire in place of the platinum standard wire. This iron wire had the effect of killing the heat in the immediate tip of the flame, with the result that each of the three lowest percentage wires had to be raised. The lowest of these, or the 0.5-per cent. wire, was raised the most; that next above a less amount; and the upper one of the three the least of all. The three upper percentage wires were not disturbed in their position by the introduction of the iron wire for a standard wire. The idea of thus killing the heat in the extreme tip of the flame was suggested by the principle of Sir Humphrey Davy's wire gauze.

"The iron standard wire, however, proved a source of annoyance in the use of the indicator in strong gas. It would burn out in a short time, and required to be replaced by another wire. Further experiment showed that copper wire could not be used, probably owing to its high conductivity; aluminum, likewise, has a comparatively high conducting power, and, in addition, it would not stand the heat of the flame. Finally, the use of a platinum wire of a somewhat lower gauge was found to meet every requirement, and this was adopted.

208. Advantages of the Sight Indicator.—"The advantage of the sight indicator over the usual method of testing for gas may be briefly stated as follows: With the normal working flame of a Davy or Clanny lamp burning ordinary sperm or lard oil, it makes plainly visible within the lamp the slightest change in the gaseous condition of the mine air, and indicates with great accuracy the exact percentage of gas present, in amounts varying from 0.5 to 3 per cent. Beyond this quantity the percentage of gas is estimated readily by the usual method of observing the height of the flame cap, which is then clearly discernible. No time is lost in drawing down the flame when making a test, and the risk of losing the light is eliminated. The indicator, operating continuously and automatically, reveals the presence of unsuspected gas where a test by the usual method would be considered unnecessary; a possible accident may be thereby averted. Aside from the actual determination of the percentage of gas present in the air, however, the chief advantage of such a device in a mine is its power to show constantly any fluctuation in the percentage of gas.

"The test is quickly made, as the wires respond promptly to the slightest change in the gaseous condition of the air. A change caused by the accidental setting open of a door, and the consequent derangement of the ventilating current, or the liberation of gas by a fall of roof in another portion of the mine, or an increased outflow of gas from old workings, caused by a sudden fall of the barometer, or even an increased quantity of inflammable dust in the air, will at once be shown by this silent monitor, as has been proved in several instances in the mine. It is already reported as having been the direct means of saving men's lives by indicating an unsuspected increase of gas where it was not thought necessary to stop to make a test. This will be understood when it is remembered that the device gives its indication with the normal working flame, the bright incandescence of the wires being clearly seen, notwithstanding the brightness of the lamp flame. This is a great advantage over the flame-cap method, in which it is necessary first to stop and lower the flame of the lamp to a mere glimmer before making the test. In doing this there is incurred not only the loss of time, but the risk of 'getting in the dark,' which every miner rightly dreads.

"The appreciation of the value of this device for the purpose named is shown by the fact that special lamps have been designed for its use in England and also in France, because the mining laws of these countries forbid the use of an unbonneted Davy lamp in a gaseous mine, and it was thought best to design a special lamp in each case. Fig. 61 shows the sight indicator in a Davy lamp." *

Special forms of the Clanny and Marsaut lamps (Fig. 36), having a 3.5-inch glass and admitting the air below the flame, have recently been designed, which give good results with the indicator. The special form of English lamp of the Ashworth-Hepplewhite-Gray type, designed for the indicator, is shown in Fig. 45.

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* Transactions American Institute Mining Engineers, Vol. XXXVII. pages 249–255.

THE FLAME TEST

209. The effect of gas in the atmosphere surrounding and supporting a flame, to alter both its shape and size, has been observed from the earliest times in connection with testing for gas in mine workings. Before the invention of the safety lamp or the use of the steel mill, when the naked candle flame was the only practicable source of light, the intrepid miner shading his eyes from its glare would cautiously raise this flame toward the roof, watching furtively as he did so for any increase in its height, or for the first appearance of the faint blue cap that indicated the presence of inflammable gas. It was then as now *the flame test*, though applied under conditions far more dangerous.

210. The Visible Effect of Gas on Flame.—The effect of *extinctive* gas on flame has been explained in Arts. 116 and 182; and at this time there will be treated only the visible effect of *inflammable* gas on flame enveloped in its atmosphere, as forming the basis of the flame test. When a flame is burning in an atmosphere containing a small proportion of inflammable gas, the amount being insufficient to permit of its separate inflammation, the gas in the air in immediate contact with the flame will be consumed, its combustion adding to the volume of the flame with which it is then identified and of which it forms a part. The combustion of this gas in contact with the surface of a lamp flame produces a thin envelope of pale-blue flame, which is naturally only visible above the tip of the lamp flame where a non-luminous *flame cap* is formed. The height of this flame cap has been found to vary with the proportion of gas present and its degree of inflammability as well as the inflammability of the illuminant producing the original flame. Besides the appearance of the flame cap caused by the gas present in the surrounding air, the height and to a less degree the volume of the original flame is increased as a result of the same causes as mentioned above. For any given percentage of gas both the height of the flame and that of the cap vary with the illuminant, being greater for the more volatile oils and for gas-fed flames than for the ordinary burning oils.

As a general proposition anything that affects the combustion on which the cap depends affects to a greater or less degree the height of the cap. The condition within the lamp is a most important factor in this respect. Those lamps like the unbonneted Davy that afford to the largest extent a free circulation of air give the highest flame caps for the same percentage of a gas and the same illuminant. Where the circulation in the lamp is restricted by a bonnet, the height of the flame cap for like conditions is reduced. It is owing to this fact that many good working lamps do not make good testing lamps.

211. Relation of Height of Flame Cap to Percentage of Gas.—From what has been described above, it is clear that the height of flame cap due to any given percentage of gas is greatly modified by the form of the lamp and the kind of illuminant used. In the same lamp, however, burning the same illuminating oil there is a practically fixed relation between the height of flame cap and the percentage of gas present in the air at the time of making the test. This relation is more exact the greater the freedom of circulation in the lamp; a restricted circulation interferes with the development of this law in proportion as it affects the gaseous condition of the atmosphere within the lamp. A bonneted lamp, with a direct circulation on the Eloin principle, will conform closer to the law than an unbonneted Clanny lamp with opposing air-currents. The unbonneted Davy lamp with a $4\frac{1}{2}$- or 5-inch gauze below the smoke gauze or cap, has a free circulation and gives better results in testing for gas than most other lamps, because the condition in the lamp very closely represents the condition of the outside air. A well-designed Eloin lamp also represents practically the same condition within the lamp as exists in the outer air.

As explained in Art. 206, Mr. William Galloway, by a number of experiments discovered the law that *the height of the flame cap varies as the cube of the percentage of gas present in the air, for the same conditions.* Mr. Galloway found, using a *bonneted* Davy lamp, the height of the flame cap in inches was practically $\frac{1}{70}$ of the cube of the percentage of gas present and producing the cap. The writer found in a long series of experiments that in an *unbonneted* Davy burning a good quality of sperm oil the height of the flame cap was practically $\frac{1}{36}$ of the cube of the percentage of gas present; these laws are expressed in formulas 34 and 35. The experiments of the writer were performed in the box arranged as shown in Fig. 62, which afforded exceptionally favorable conditions for obtaining an exact measurement of the gaseous condition of the atmosphere producing any given height of flame cap. To determine the height of flame cap corresponding to any given percentage of gas, formulas 34 and 35 may be written

$$\text{Unbonneted Davy, sperm oil (Beard) } h=\frac{J^3}{36}. \qquad (36)$$

$$\text{Bonneted Davy, colza oil (Galloway) } h=\frac{J^3}{70}. \qquad (37)$$

The height of the cap depends to a certain extent also on the height of the original flame. The above formulas are based on data derived from the smallest possible flame, which is practically $\frac{1}{8}$ inch in height. Prof. Clowes has drawn attention to what he calls the maximum height of cap for any given percentage of gas, which he states may be obtained by drawing down the wick till the cap attains its greatest height. Such a standardizing of the flame in making a test in the mine can hardly be considered as practicable, owing to the risk incurred of losing the flame. For all practical purposes this is an unnecessary refinement in making a test in the mine. As explained (Art. 102), gas has a tendency to stratify and move in veins, which frequently cause some considerable variation in the results of tests that should seemingly agree. Occasionally it will happen that a lamp will fill with flame, as it has in the writer's experience, which as quickly passes away, so that there is only a trace of gas remaining, and this without moving the lamp. There is always an increasing percentage of gas shown on the lamp as it is approached closer to the source of the feeder.

It is owing to these conditions in the mine that a fire boss using the ordinary flame test and the common Davy lamp will frequently report "no gas," when in reality there is a large quantity of gas being given off, which only requires some slight derangement of the ventilating current to produce a dangerous atmosphere. With the large volumes of air now being circulated in mines it is more necessary than ever before that the lamp of the fire boss should detect the smallest possible percentages of gas, and indicate by some simple ready means of measurement the exact percentage of gas present in the air, so as to eliminate once for all the irresponsible custom now in use of guessing the height of the cap, and the inability of the observer to see the smaller caps.

212. Flame Caps of Different Illuminants in Different Lamps.—In general it may be said the common burning oils are better adapted to detect the larger percentages of gas, say from 2.5 to 6 per cent., while the lighter mineral oils, alcohol and hydrogen gas, are of use in detecting the lower percentages, from 0.25 to 3 per cent. The form of lamp used also modifies the height of the cap for any given percentage of gas. The following table is of interest in comparing the heights of flame caps produced by different illuminants in different lamps. It will be observed benzoline burned in the Ashworth-Hepplewhite-Gray lamp presents the widest range of any of the other illuminants, but is not as sensitive in the detection of a slight gaseous change, because the difference in the heights of cap produced by such a change is small.

TABLE 25

HEIGHTS OF FLAME CAPS FOR DIFFERENT ILLUMINANTS AND LAMPS—REDUCED FLAME

Illuminant	Lamp	Percentages of Gas									
		.25	.50	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0
		Heights of Flame Caps (Inches)									
Sperm or lard oil	Davy (unb't'd)					.22	.43	.75	1.75	3.50	
Colza	Davy (bon't'd)						.22	.38	.88	1.80	3.20
Colza	A-H-G						.20	.30	.50	1.20	2.70
Benzoline	Ashworth	.20	.30	.40	.50	.60	.70	.80	1.00	1.20	1.40
Naphtha (benzine)	Wolf			.35	.40	.52	.72	1.16	2.76		
Alcohol	Ashworth	1.10	1.90	3.00							
Alcohol	Pieler	1.20	2.00	3.00	4.00	5.00					
Hydrogen	Clowes-A-H-G	.90	.90	1.10	1.20	1.40	1.75	2.30			

For the purposes of testing, the hydrogen flame possesses the advantage that it is not as easily extinguished by the presence of carbon dioxide and other extinctive gases. On the other hand, alcohol and the light mineral oils are very susceptible to the action of these gases, which is one of the chief objections to their use for the work of testing. There is some difference in the observed heights of the flame caps as recorded by different authorities, owing chiefly to the use of different lamps, different grades of illuminants, and possibly also a difference in the quality of gas tested, but the differences are not important. What is required in the practical work of testing for gas in the mine is a thorough acquaintance with the lamp and oil used, in respect to the behavior of the flame and the heights of the several caps as indicating the percentages of gas present. Of more importance still is the ability to rightly interpret these caps or percentages as indicating the degree of danger in the mine air with respect to gas and dust, remembering that *percentage* is only another name for *condition* in the mine. It matters little whether such percentage conforms absolutely to that given for the same height of cap in a test of the gas in the laboratory. In the practical work of testing in the mine the measured height of flame cap is a valuable index of the explosive condition of the mine air, and *percentage* is merely a convenient name describing such conditions in a manner that will show their relative danger. It is therefore essential that some accurate means be employed for measuring the exact heights of the caps formed, or otherwise accurately gauging the gaseous condition of the air.

213. Measurement of Flame Caps in Testing Lamps.— For the purpose of accurately measuring the heights of the hydrogen flame used for testing for gas in the

Clowes hydrogen lamp (Art. 173), Prof. Clowes employed a ladder scale, which is shown attached to the lamp vessel in Fig. 43. This scale is shown more in detail in Fig. 63, together with a scale of inches at the right to show the actual heights of the several flame tips. As shown, the original height of the flame is .4 inch above the top of the burner, from which point all measurements are

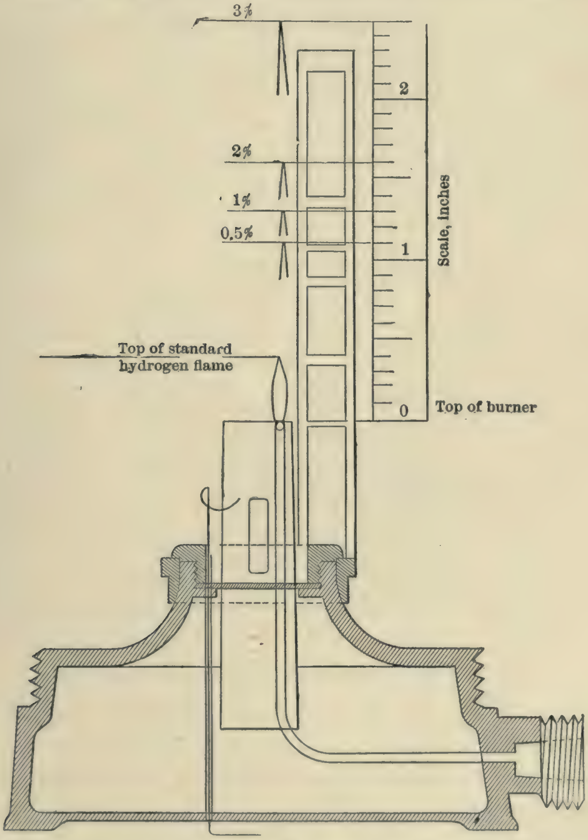

FIG. 63.—Section of Oil Vessel of Clowes Hydrogen Lamp, showing Attached Scale for Measurement of Flame Caps

made. The flame is adjusted in air free from gas, so that its tip just reaches the top of the first cross-bar. The cross-bars above this are arranged at such heights as to indicate 0.5, 1, 2, and 3 per cent. of gas respectively, each of these bars, however, being set exactly .2 inch below the tip of the corresponding flame, so that the bar will readily appear as a black line across the flame near its tip. Thus the height of the flame tip for 3 per cent. of gas is 2.5 inches, while the top of the corresponding cross-bar is 2.3 inches; this difference is readily gauged by the eye. When more than 3 per cent. of gas is present, the determination is made with the oil flame as follows: the wick being first raised and lighted, the supply of hydrogen is then turned off and the wick is drawn down, so that the oil flame would only be .1 inch high in air free from gas. The heights of cap corresponding to different percentages of gas are then as follows: 4 per cent., 0.6 inch; 5 per cent., 1.3 inches; 6 per cent., 2.8 inches; these heights of cap for the given percentages being obtained in the Ashworth type of the Clowes lamp. There will be some slight difference in the heights of cap for the same percentage of gas when drawing the air from above the lamp having the lower inlet openings in the tubes closed, because of the retardation of the circulation in the lamp.

In the Pieler lamp (Fig. 39) and the Chesneau lamp (Fig. 40) scales for the estimation of the cap are arranged on the outside of the lamp. The platinum-wire scale of the Beard-Mackie lamps (Art. 174), arranged within the lamp, acts on a different principle from a simple measuring scale. The cross wires here glow at heights somewhat above the tip of the flame (Art. 205). This scale is used with the normal working flame, which is not reduced when testing with the indicator.

214. Care of Lamp.—Every fire boss, fireman, or mine examiner should take the entire care of his own lamp, which must be thoroughly cleaned after each shift. Particular care must be taken to brush out the gauzes; these should be removed from the lamp for the purpose. Two kinds of brushes are in common use: the bristle brush shown at (*a*) (Fig. 64) and the metallic brush shown at (*b*). At (*c*) is shown the common straight gauze of the Davy lamp, and at (*d*) the conical gauze mostly used in Marsaut and Mueseler types. Each of these gauzes is provided with a gauze cap or *smoke gauze*, as it is sometimes called. It is important to remove this cap and brush out the soot and dust that collects there, but care is required in doing this not to injure the mesh of the gauze. The indent or crease shown in the cap of the gauze at (*d*) is to prevent the cap from being pushed too far down on the main gauze. The glass (*e*) should be cleaned and rubbed dry. The wick should be carefully trimmed, a new wick being put in the lamp at least once

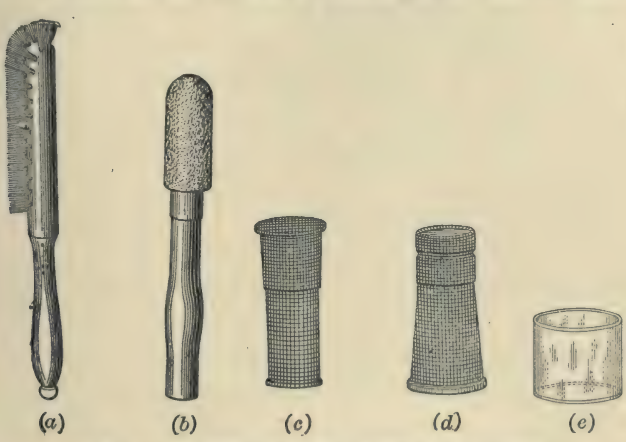

FIG. 64.—Lamp Brushes, Gauzes, and Glass

a week and oftener if the oil shows a tendency to thicken and gum or make the wick greasy. Short wicks often renewed are better than long wicks, and give a better light. The lamps should be filled, not too full, with a good quality of sperm or lard oil, to which the fire boss has added half its volume of coal oil, or kerosene having a flashing point not lower than 80° F.

215. Examining a Mine for Gas.—When examining a mine or any portion of it for gas, the work should begin at the intake end and proceed *with the air*. Care is needed to avoid the possibility of walking into a body of firedamp. This will sometimes happen when a fire boss enters a room or chamber where the circulation is slack. The gas may be working out from the room in a thin layer along the roof, and the quick passing of a person under this may disturb the gas and cause it to descend behind him as he goes towards the face of the room unconscious of his danger. On suddenly becoming aware of the presence of the gas and turning to retreat he finds to his dismay the whole place filled with gas. He is fortunate if he can escape from the disturbed atmosphere of the room by a nearby cross-cut into another chamber as yet undisturbed, and through which he may perchance reach the purer air of the entry. For lack of sufficient caution and in haste to complete his morning round many an unwary fireman has been thus suddenly entrapped in a body of gas from which retreat is uncertain and dangerous.

The approach to a known body of gas should always be made on the intake side to avoid being enveloped in the tail of gas before reaching the seat of the trouble, and to have a clear retreat open should it be necessary to withdraw quickly. The examination of a mine before the men are allowed to enter for work should be thoroughly executed. The person or persons making this examination should be conscientious in the performance of the work, and no place should be assumed to be free from gas except for a good and valid reason that would justly warrant such a conclusion. The fire boss is responsible for many lives and only such men as are fully trustworthy should be chosen for the work.

216. Making a Test for Gas with a Davy Lamp.—Every test should be made with caution, even where gas is not suspected. There are two methods of making the common flame test with the Davy lamp: one by observing the cap formed by the gas when the flame is drawn down to a mere glimmer, and the other by observing the increase in the height of the normal working flame due to the presence of gas. The **cap test** or the test by the **reduced flame** is by far the one most commonly used and the most reliable. Both methods, however, are crude approximations, permitting of much guesswork on the part of the examiner, often making him the autocrat of the situation, and loading him with responsibilities he is, or should be, unwilling to assume.

When about to make a test with the reduced flame, the lamp having been prepared in the manner described (Art. 214), the flame is first drawn down with the pricker to a glimmer varying from $\frac{1}{8}$ to $\frac{1}{4}$ inch in height, according to the individual preference of the examiner. The lamp is then raised cautiously in an upright position towards the roof. Fig. 65 well illustrates the characteristic pose when examining a gas pocket in the roof. It is readily understood that nothing less than a 1-inch or a 1.5-inch cap would be detected in this position of the lamp. When examining for a thin layer of gas at the roof, in a chamber or heading, it is necessary to disturb the gas slightly with the cap or a movement of the hand, or, as is often done, by blowing against the roof. Then, holding the lamp upright in one hand and screening the main body of the flame with the other, it is possible to detect a cap somewhat less than ½ inch in height, indicating 2.5 per cent. of gas (Table 25). The practice of turning the lamp on its side and drawing or waving it along the roof is a dangerous one and ought to be wholly discontinued. The lamp should always be

Fig. 65.—Making a Test for Gas

held upright when making a test. When making a test in an air-current it is necessary to shield the flame from the direct force of the wind; this is best accomplished by turning the back to the wind and holding the lamp in front of the person in a protected position. The procedure is the same when testing with the normal flame, but in this case the height of the flame is observed instead of the cap and the percentage is determined and reported according to the experience of the observer.

217. Comparative Merits of the Flame Test and the Sight Indicator.—In the use of the sight indicator it becomes unnecessary to make an actual test for gas, since the indicator reveals constantly the gaseous condition of the mine air. This is done with the normal working flame, thus avoiding the risk of losing the light, which must always be incurred when it is necessary to make a test with a reduced flame. The indicator often reveals a change in the gaseous condition of the air too small to be detected on the flame of the lamp by the unaided eye, but which is important because it betrays the actual condition of the mine in this respect. The existence of an accumulation of gas is indicated at a distance from the place where it is found and danger is often thus avoided.

It has been so long the custom to test for gas in the mine in a crude way that many still hold to the belief that there is no danger from this source as long as the proportion of gas is not sufficient to produce a "cap," which means, in ordinary mining practice, anything under 3 per cent., because the average miner does not call anything less than this "gas." The report of the early-morning examination made when the mine was idle and the air passing through the workings clear and free from dust reads "no gas"; and two hours later an explosion wrecks the mine. Such was the sad tale of the terrible explosion in the Klondike workings of the Rolling Mill Mine, at Johnstown, Pa., on the morning of July 10, 1902, when 112 souls were ushered into eternity, in a mine that had just been examined by authorized and competent fire bosses who had reported "no gas." It requires no argument to prove that such a system of testing is wrong. The experiments of Galloway have proved that air containing but .892 per cent. of marsh gas is explosive (Art. 115), while the still more important experiments of Hall proved quite conclusively that some dusts, under certain conditions, are of themselves explosive and that the ignition of such dust may be caused by a flame of sufficient intensity in the entire absence of marsh gas or other inflammable gases (Art. 131).

It is of the utmost importance to notice that an atmosphere that may seem to be perfectly safe when the mine is examined in the early morning, may be changed into a dangerous atmosphere when the mine is in operation. This is particularly true in the working of a soft, inflammable coal, but it is likewise true, though to a less degree, in an anthracite mine. The writer has observed a difference of ½ per cent. between the reading of the sight indicator at the roof of a chamber and one taken at the same time and place near the floor in a cloud of anthracite dust caused by the loading of a car, the higher reading being at the floor; there was 2 per cent. of gas at the roof and 2.5 per cent. at the floor. In another instance the indicator showed a gradual but slow increase of the general gaseous condition of a certain section of a mine, from day to day, and the fire boss laid this gradual and steady increase to the effect of a coming squeeze, which proved to be only too true, it becoming necessary in a few days' time to draw the track from a portion of this section. In another instance, by the timely warning of the indicator, which showed an increase of 1 per cent. over the usual reading in the air returning from a certain panel, three men were stopped from running into a body of gas that had accumulated between shifts by the accidental setting open of a gate by men leaving the mine. The men had open lights and would have been severely burned if not killed but for the warning of the indicator.

There is a tendency among all miners more or less to use too high a flame in a safety lamp. This is a bad practice, because of the smoking and sooting of the gauzes. The working flame of a safety lamp should not exceed from $\frac{3}{4}$ to 1 inch, depending on the condition of the mine air and the strength of the air-current. When the state of the air approaches an explosive condition, or in a strong current of air, the height of the flame should be reduced accordingly. The use of a poor or inferior illuminating oil gives rise to sooting, which impairs the efficiency of the sight indicator and endangers the lamp by clogging the gauze. With a good quality of sperm or lard oil in an unbonneted Davy lamp, with a safe flame that will not smoke the gauzes, there is no trouble from "sooting" in the use of the sight indicator. But it is always true that a good tool in the hands of a poor workman is capable of no better results than a bad tool in the hands of a good workman.

218. Measurement of Gas in Mines.—Strange as it may seem, the common practice of reporting the quantity of gas found in a chamber is even more crude than the method of its detection. When gas is found at the face of a chamber or heading, the quantity is estimated by the number of inches down from the roof where the first appearance of a cap was discovered; this quantity is reported as 6, 8, or 12 inches of gas, as the case may be. Fig. 66 illustrates a possible condition at the working face of a room where a considerable quantity of gas is issuing from the coal. As the gas transpires from the face of the coal it rises towards the roof, as indicated by the small arrows and the dotted lines. The larger arrows close to the floor represent the flow of fresh air toward the face, where it rises and mixes with the gas. The circulation shown in the figure is not rapid, the movement of the air and gas being scarcely perceptible. It is evident that a test made for gas under these conditions would show almost any percentage of gas, according to the position of the lamp and the

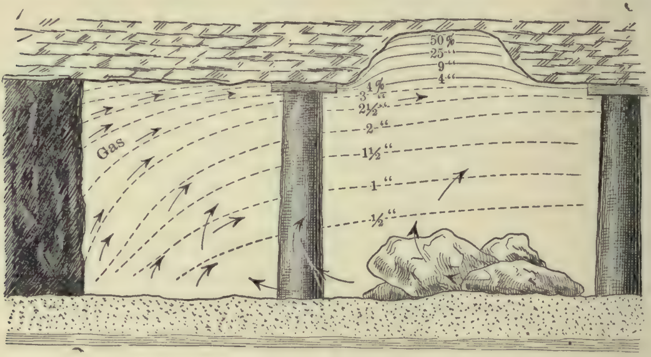

FIG. 66.—Showing Condition with Respect to Gas at Face of a Chamber

delicacy of the test. The illustration shows a roof fall between the timbers and a dangerous pocket of gas in the cavity left in the roof. There would be a good opportunity for a hasty fire boss to lose his light here by incautiously raising his lamp into this pocket. With some lamps an explosion might be caused by the sharp gas entering a lamp filled with nearly pure air from the floor of the chamber. This is more apt to occur with a closely bonneted lamp than with the unbonneted Davy, but the latter must not be moved quickly when *flaming*, which occurs in an atmosphere containing between 5 and 6 per cent. of pure marsh gas.

When a current of air containing a certain per cent. of gas is flowing in an airway, at a distance from the point where the gas entered the current, the mixture of gas and air is more uniform, and it is possible to estimate with some degree of approximation the quantity of gas in the current, or the quantity of gas given off in that section of the mine each minute. But in a room or heading or any other place in the mine where gas is being generated, as illustrated in Fig. 66, it is impracticable to attempt to form any estimate of the quantity of gas being given off, because the conditions are not uniform. In a general way the report that a cap was obtained, say 6 inches from the roof, at a distance of 10 feet from the face, or 20 feet from the face, indicates roughly the condition of the room with respect to gas. It shows whether the place is sufficiently safe to enable men to work there, and suggests the precautions it will be necessary to observe with respect to lights at the face of the room.

The question is sometimes asked, In what percentage of gas is it safe or possible for men to work? This question cannot be answered in a way that would apply to all mines, since the character of the gas, the degree of inflammability of the coal, the intelligence and experience of the men, the character of the ventilation, and many other conditions would modify the answer to be given to such a question in any particular case. Men should not be permitted to work in any percentage of gas that approaches a dangerous condition when it is practicable to reduce the percentage of gas in the air. If this is impracticable, only experienced men should be allowed to enter the place and every precaution should then be taken to safeguard the work. Men have mined coal in the dark because it was very unsafe to approach a lamp to the face of the breast. The work of mining under these conditions, however, is very hazardous, as the slightest occurrence may result fatally. It should be possible by some means to improve the situation and render the work fairly safe. Ordinarily the percentage of gas in the air coming from the face should not exceed 2 per cent. for anthracite and 1 per cent. for bituminous mines, but the particular character of the coal or of the gas may alter this.

CARE OF MINERS' SAFETY LAMPS

219. All safety lamps used in a mine, except those of the fire bosses (Art. 214), should belong to the company operating the mine. In this way the management will be able to maintain proper supervision and control of the lamps, which is of the utmost importance. It will also be wholly at the option of the management what type or types of lamps shall be used. By assuming the full charge and responsibility of the safety lamps, the management secures to itself the sole right to lock and unlock the lamps.

220. Requirements.—The proper care of a safety lamp requires that it shall be thoroughly cleaned, filled, and trimmed at the end of each shift. This work should be done in a separate, properly equipped lamp house. Each lamp should at least be carefully inspected by a competent person before being given out for use in the mine. Whenever practicable each lamp should be exposed to an atmosphere of firedamp in a test box or chamber, to ascertain if the lamp is in perfect condition before it is taken into the mine. Where a mine is particularly gaseous the testing of lamps should be made imperative, also a careful inspection. After the lamp is lighted it should be subjected to the test box a sufficient length of time to prove its security in gas (Art. 155).

As explained in Arts. 187 and 214, a good quality of sperm or lard oil mixed at the mine with kerosene (coal oil) having a flashing point not less than 80° F. should be used in the proportion of two volumes of the former to one volume of the latter. Short wicks (Arts. 189, 214) of good quality should be used, and these should be often renewed to insure that the oil is fed properly to the flame.

The lamp should be examined to ascertain that it is properly put together, and then locked by a duly authorized person. Each lamp should bear a number corresponding to the check number of the man who uses it, and when returned to the lamp house a check bearing the same number is given to the man returning the lamp. As far as practicable the same lamp should be given to the same person from day to day.

221. The Lamp House.—There are several different arrangements of lamp houses that vary somewhat in detail, but all possess certain features in common; namely, a passageway for the men receiving or returning lamps, convenient lamp racks, a room for cleaning and filling the lamps, furnished with proper benches or tables and the necessary apparatus. In many lamp houses there is a separate room for repairing broken or injured lamps.

The arrangement shown in Fig. 67 offers every facility for receiving, inspecting, cleaning, filling, storing, lighting, and delivering lamps. On coming out of the mine the men pass into and through the passage *a*, leaving their lamps at the windows marked *o*, and receiving in return a brass or leather check bearing the same number as the lamp returned. The lamps thus received are examined in the room *b*, where they are unlocked and taken apart. The gauzes of the lamps are thoroughly cleaned with a good brush (Fig. 64), the glasses polished, and the oil and dirt wiped from the lamp. In case the number of lamps in use is large, a special cleaning machine having rotating brushes is often installed in this room. If lamps are found on inspection to require repairs, they are held in this room till this can be done, work benches for the purpose being located at *w* on each side of the room and supplied with the necessary tools and equipment. The cleaned parts of each lamp are assembled at *x*, and passed through openings or under the light partition *ss* to the benches *yy*, where they are filled with oil drawn from the taps shown above this bench. The lamp house is built of 13-inch brick walls and a slate roof. The house is heated by steam from the power plant. In a small brick addition is built a suitable oil tank *n*, having a capacity of about 150 gallons of oil. The oil is pumped into this tank from barrels on the outside of the building. The tank *n* is set at a sufficient

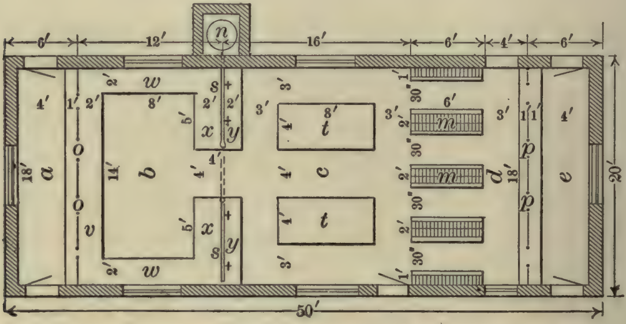

FIG. 67.—Showing Arrangement of Lamp House

height to enable the oil to flow through the pipe *s* leading from the bottom of the tank and supplying the taps for filling the lamps. After filling, the lamps are removed to the tables *tt* where the wicks are trimmed and new wicks supplied if required and the lamps put together; or the top of each lamp may be left off and set away with

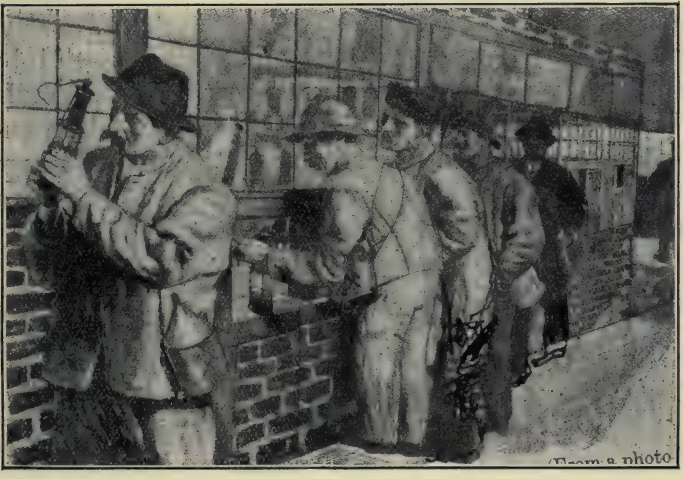

FIG. 68.—Receiving Lamps at the Lamp House

the lamp in its proper place in the racks *m*. The racks shown in the figure will accommodate 480 lamps; each rack is 5 shelves high and each shelf contains places for a dozen lamps. The boxes or pigeonholes are numbered with numbers corresponding to the numbers on the lamps. Each lamp after being cleaned and filled is returned to its proper place in the rack, where it is readily found when needed in the morning.

When applying for lamps the men enter and pass through the passage *e*, receiving their lighted lamps at the windows *pp,* in return for the numbered checks given them the night before. Fig. 68 is a view of the interior of such a lamp house, and shows the men going on shift in the act of receiving and examining their lamps. Each lamp is lighted quickly at a burning jet, screwed together and locked by the attendant before being given out. The floor of the lamp house is of cement, the tables and benches are supported on iron frames or brackets and have slate tops, the lamp racks are iron. The house should be lighted with electric incandescent lamps. No one should enter the lamp rooms, to which there is but one door, but those who have been regularly appointed to have charge of the work. The house should be kept absolutely clean in all its appointments.

ADDENDA

STANDARDS OF WEIGHT AND MEASURE

No one can read the History of Standard Weights and Measures of the United States, prepared and issued by the Bureau of Standards, Washington, D. C., without being deeply impressed with the importance of uniformity in all standards in use throughout the world.

Unfortunately much confusion has attended each successive attempt on the part of different countries to establish a *natural standard of reference* such that its value could be readily restored in the event of the loss of the original standard.

The French or metric unit of length, the *meter*, was intended to be one ten-millionth part of a meridian quadrant of the earth. Subsequent measurements, however, showed not only that the meridians measured were of unequal length, but the remeasurement of the meridian selected previously by the French committee gave a result that differed from the first measurement by about $\frac{1}{40}$ of one per cent. This natural standard was therefore abandoned.

The English unit of length, the so-called *standard imperial yard*, was originally, by act of Parliament, made derivable from the length of a simple seconds pendulum, at sea level, London, which was stated as being 39.139 inches. The standard yard was therefore made $\frac{36,000}{39,139}$ of the length of the above seconds pendulum.

However, the original British standard having been rendered useless by the fire that destroyed the Houses of Parliament (October, 1834), a new standard was constructed by the committee having the work in charge without reference to the legalized length of the seconds pendulum. The length of the new standard was established by comparisons with other standards, said to be true copies of the original standard destroyed. Here again the idea of a *natural standard* proved to be more a sentiment than an actual reality.

Experience has proved that it is always possible to gauge *volume* more closely by weighing than by the most careful measurement. For this reason the volume of a given weight of distilled water, at its maximum density (4° C.) or at any other stated density, in a vacuum or in air, etc., as the case may be, has been found a convenient basis of comparison when estimating weight or volume. Units of weight and of volume are therefore quite generally expressed in terms of the weight and volume of water under stated conditions.

Unfortunately for the securing of uniformity, the weight of water has not been determined with great exactness, and for this reason the unit weight assumed has differed in different countries. This is apparent when comparing the legal standards of Great Britain and France. For example, in Great Britain the standard gallon is declared to be 10 pounds of water at 62° F., weighed with brass weights, in air at 62° F., barometer 30 inches, being in volume 277.274 cubic inches. This volume of the gallon is based on an assumed weight of distilled water as follows:

1 cu. in. water,	4° C., in vacuum......	253.000	grains.
1 " " "	62° F., " "	252.724	"
1 " " "	62° F., in air (62° F., bar. 30 in.), brass wts..	252.458	"

Then, for the volume of 10 pounds of distilled water at 62° F., weighed with brass weights, in air at 62° F., barometer 30 inches, since 1 pound = 7,000 grains,

$$\frac{10 \times 7{,}000}{252.458} = 277.274 \text{ cu. in.} \quad \text{(English standard gallon)}$$

Comparing the above weight of 1 cubic inch of distilled water, at maximum density (4° C.), in vacuum, with the assumed unit weight in the French system

1 liter (cu. decimeter) water, 4°C., in vacuum = 15,432.36 grs.

In the English system (1 meter = 39.37079 inches *); then 1 liter = 61.02705 cubic inches, and the weight of 1 cubic inch of water (4° C.), in a vacuum, on the French basis, is

$$\frac{15{,}432.36}{61.02705} = 252.877 \text{ grains}$$

The unit weight of water adopted by the French is therefore lighter than that adopted by the English, for the same conditions.

As far as the United States is concerned, the chief importance attaches to the comparison of the English and French standards, since the standards in common use in this country have for the most part been brought from England, and for the further reason that the French or

---

* The value of the English meter is sometimes given as 39.370113 inches.

metric system is coming into general use, and will eventually be the basis of comparison for *all* standards, if not the adopted standard in all countries.

The following are the units of *length, weight,* and *volume* in common use in France, England, and the United States, together with their equivalencies:

In England:

The standard *yard* (36 inches) is $\frac{3,600,000}{3,937,079}$ of a meter.

The *pound* avoirdupois (7,000 grains) = 453.5924277 grams.

The standard *gallon* (277.274 cubic inches) = 4.54346 liters.

In France:

The *meter* = 39.37 inches (United States); 39.37079 inches (England).

The *kilogram* = 2.204622341 pounds; 15,432.356387 grains.

The *liter* = .26417 gallons (United States); .220097 gallons (England).

In the United States:

The *yard* (36 inches) is $\frac{3,600}{3,937}$ of a meter.

The *pound* avoirdupois (7,000 grains) = 453.5924277 grams.

The *gallon* (231 cubic inches) = 3.78543 liters.

The difference in the values given to the meter in the United States and in Great Britain, each expressed in inches, shows the United States inch to be slightly longer than the English inch.

In connection with the comparison of standards, the density of distilled water at different temperatures is important. Taking its density at 4° C. as unity or 1, the relative density of distilled water at any temperature is expressed by the formula

$$D=\frac{1{,}000T}{500^2+T^2},$$

in which

D = density of distilled water at T degrees absolute;

T = absolute temperature of the water (deg. Fahr.)

For example, the density of water at 62° F., or an absolute temperature of $T=460+62=522°$, is

$$D=\frac{1{,}000\times 522}{500^2+522^2}=.999073$$

The actual density at this temperature is .998908. Likewise for the density at 212° F., or $T=460+212=672°$,

$$D=\frac{1{,}000\times 672}{500^2+672^2}=.95783$$

The actual density in this case is .95866. The error here, though greater than before, is less than .09 per cent.

THE METRIC SYSTEM

The metric system as it is known to-day is practically not different from the original French system of weights and measures. The principal features of the metric system were embodied in a report made by the Academy of Sciences to the French National Assembly in 1791. It was not, however, until fifty years later, in 1840, that the use of the system became general in France. Other countries later adopted the metric system as a standard or permitted its use. In 1866 the use of the metric system was made lawful in the United States by act of Congress.

The metric system is a decimal system, all multiples or divisions of the adopted units being expressed in tens. The principal unit or base of the system is the **meter**, being the *unit of length.* The system now has no natural standard, its length being defined and perpetuated by certain artificial platinum and platinum-iridium standards preserved in the Archives, at Paris, and in the vault of the International Bureau of Weights and Measures, near Paris, France.

The *unit of weight* (mass) is the weight or mass of distilled water at maximum density whose volume is equal to one cubic decimeter, the weighing being performed in a vacuum in order to eliminate the buoyant effect of the air, which varies with the temperature and atmospheric pressure. This unit weight is called a **kilogram**, being equal to one thousand grams.

The *unit of capacity* is the volume of the mass of one kilogram of distilled water at its maximum density and weighed in a vacuum. This unit volume is called a **liter** and contains one thousand cubic centimeters.

Since 1 cubic centimeter of water weighs 1 gram, the specific gravity of any substance, referred to water as unity, is the weight per cubic centimeter of the substance in grams, or the weight per liter in kilograms. For example, the specific gravity of alcohol being .793, 1 liter of alcohol weighs .793 kilograms; or, sulphuric acid having a specific gravity of 1.75 weighs 1.75 kilograms per liter, or 1.75 grams per cubic centimeter.

Since the establishment of the International Bureau of Weights and Measures, May 20, 1875, much has been accomplished towards securing more uniform and permanent standards. By an agreement duly signed by seventeen of the principal governments, the International

Bureau was located just outside of Paris, on a plat of ground set aside for the purpose by the French government and declared to be neutral ground.

New standards were made by the international committee, of an alloy consisting of 90 per cent. platinum and 10 per cent. iridium, which were exact copies of the meter and kilogram standards of the Archives, Paris. Of these copies, the meter and kilogram that agreed most closely with those of the Archives were deposited as the international standards in a subterranean vault under one of the buildings of the International Bureau. This vault can only be opened when three officials are present, each bearing a different key. The other standards were then distributed to the several governments forming the bureau, after all had been approved by a general conference held at Paris, September, 1889.

FUNDAMENTAL EQUIVALENTS

(UNITED STATES LEGAL STANDARDS)

The following are given as the *fundamental units* and *equivalents* of metric weights and measures by the American Bureau of Standards, Washington, D. C.

Unit of length, meter =39.37 inches (United States).
Unit of capacity, liter =1 cubic decimeter.
Unit of weight, gram =weight of 1 cubic centimeter of pure water at maximum density (4° C.)
Gallon, U. S. (Winchester) =231 cubic inches.
Bushel, U. S. =2,150.42 cubic inches.
Pound (avoirdupois) =7,000 grains.
" " =453.5924277 grams.
Gram =15.432356387 grains.
Pound (troy, apothecaries) =5,760 grains.

The *grain* is the basis of comparison for *avoirdupois, troy,* and *apothecaries'* weights, being the same in each.

CONVERSION TABLES

UNITED STATES AND METRIC WEIGHTS AND MEASURES

LINEAR

Inches	× 25.40005 = millimeters	Millimeters	× .03937 = inches
“	× 2.54000 = centimeters	Centimeters	× .39370 = “
“	× .25400 = decimeters	Decimeters	× 3.93700 = “
“	× .02540 = meters	Meters	× 39.37000 = “
Feet	× .30480 = “	“	× 3.28083 = feet
Yards	× .91440 = “	“	× 1.09361 = yards
Rods	× 5.02921 = “	“	× .19884 = rods
Miles	× 1609.35000 = “	“	× .00062 = miles
“	× 160.93500 = decameters	Decameters	× .00621 = “
“	× 16.09350 = hectometers	Hectometers	× .06213 = “
“	× 1.60935 = kilometers	Kilometers	× .62137 = “
Rods	× .00503 = “	“	× 198.83838 = rods
Yards	× .00091 = “	“	× 1093.61111 = yards
Feet	× .00030 = “	“	× 3280.83333 = feet
Miles	× .16093 = myriameters	Myriameters	× 6.21370 = miles

SQUARE

Inches	× 645.16254 = millimeters	Millimeters	× .00155 = inches
“	× 6.45163 = centimeters	Centimeters	× .15500 = “
Feet	× 929.03406 = “	Decimeters	× 15.49997 = “
“	× 9.29034 = decimeters	“	× .10764 = feet
Yards	× 83.61307 = “	Meters	× 10.76387 = “
“	× .83613 = meters	“	× 1.19599 = yards
Rods	× 25.29295 = “	“	× .03954 = rods
Acres	× 4046.87235 = “	“	× .00025 = acres
“	× .40469 = hectares	Hectares	× 2.47104 = “
Miles	× 258.99983 = “	“	× .00386 = miles

CUBIC

Inches	× 16.38716 = centimeters	Centimeters	× .06102 = inches
Feet	× 28.31702 = decimeters	Decimeters	× 61.02338 = “
“	× .02832 = meters	Meters	× 35.31445 = feet
Yards	× .76456 = “	“	× 1.30794 = yards

CAPACITY

Cu. inches	× 16.38716	= milliliters	Milliliters	× .06102	= cu. inches
“ “	× 1.63872	= centiliters	Centiliters	× .61023	= “ “
“ “	× .16387	= deciliters	Deciliters	× 6.10234	= “ “
“ “	× .01639	= liters	Liters	× 61.02338	= “ “
Cu. feet	× 28.31702	= “	“	× .03531	= cu. feet
“ “	× 2.83170	= decaliters	Decaliters	× .35314	= “ “
“ “	× .28317	= hectoliters	Hectoliters	× 3.53145	= “ “
“ “	× .02832	= kiloliters	Kiloliters	× 35.31446	= “ “

LIQUID MEASURE—U. S.

Minims	× .06161	= milliliters	Milliliters	× 16.23060	= minims
Fluid dr.	× 3.69671	= “	Centiliters	× 2.70510	= fluid dr.
Fluid oz.	× 2.95737	= centiliters	Deciliters	× 3.38138	= fluid oz.
Gills	× 11.82948	= “	Liters	× 8.45344	= gills
Pints	× 4.73179	= deciliters	“	× 2.11336	= pints
Quarts	× .94636	= liters	“	× 1.05668	= quarts
Gallons	× 3.78543	= “	“	× .26417	= gallons
Barrels	× 11.92412	= decaliters	Decaliters	× .08386	= barrels
“	× 1.19241	= hectoliters	Hectoliters	× .83863	= “

DRY MEASURE—U. S.

Pints	× .55061	= liters	Liters	× 1.81616	= pints
Quarts	× 1.10123	= “	“	× .90808	= quarts
Pecks	× 8.80982	= “	“	× .11351	= pecks
Bushels	× .35239	= hectoliters	Hectoliters	× 2.83774	= bushels

AVOIRDUPOIS

Drams	× 1.77184	= grams	Decagrams	× 5.64382	= drams
Ounces	× 2.83495	= decagrams	Hectograms	× 3.52739	= ounces
Pounds	× 4.53592	= hectograms	Kilograms	× 2.20462	= pounds

APOTHECARIES

Grains	× 6.47989	= centigrams	Grams	× 15.43236	= grains
Scruples	× 12.95978	= decigrams	Decagrams	× 7.71618	= scruples
Drams	× 3.88794	= grams	“	× 2.57206	= drams
Ounces	× 3.11035	= decagrams	Hectograms	× 3.21508	= ounces
Pounds	× 3.73242	= hectograms	Kilograms	× 2.67923	= pounds

TROY

Grains	× 6.47989	= centigrams	Grams	× 15.43236	= grains
Pennywts.	× 15.55174	= decigrams	Decagrams	× 6.43015	= pennywts
Ounces	× 31.10347	= grams	Hectograms	× 3.21508	= ounces
Pounds	× 37.32418	= decagrams	Kilograms	× 2.67923	= pounds

CONSTANTS AND UNITS OF REFERENCE

Aside from uniformity of standards, it is apparent to all engineers and students of science that similar uniformity and accuracy are needed in respect to the numerous constants and reference units employed in all scientific calculations. Not only is this desirable but absolutely essential in order that true progress shall be made. Much confusion often arises in comparing notes referred to different standards, which would be in large part or wholly avoided by the use of generally accepted constants or equivalents.

As far as possible the constants used in this volume are those that have been most generally accepted. The determinations of the weight of air and the densities of gases by Regnault; the pressure of the atmosphere at different elevations above sea level, by Airy; the aeronautic observations of Gay-Lussac, Glaisher, and Herschel; the heat determinations of Regnault, and Favre and Silbermann, have all furnished reliable data for the calculation of these constants.

The weights of unit volumes of the common standards, **water**, **air**, **hydrogen**, and **mercury**, are given in *grams*, *pounds*, and *grains*, in the table on the opposite page.

It has been the aim throughout to make all values and constants used correspondent, or such as are derivable from each other. For example, the weight of 1 cubic inch of water (4° C.) being .03613 pound, and the specific gravity of mercury (32° F., standard) being 13.593, the weight of 1 cubic inch of mercury (32° F.) is

$$.03613 \times 13.593 = .49111 \text{ lb.}$$

Again, the normal barometric reading at sea level being 29.925 inches of mercury (Table 7), the corresponding atmospheric pressure is

$$.49111 \times 29.925 = 14.696 \text{ lb. per sq. in.}$$

	Volume	Weight		
		Grams	Pounds	Grains
Water (max. dens., 4° C.), standard	1 liter	1,000.00	2.20462	15,432.36
Do., calculated	1 cu. in.	16.39	.03613	252.89
Do., “	1 cu. ft.	28,317.01	62.42830	436,998.10
Water (freezing, 0° C.), calculated	1 liter	999.97	2.20456	15,431.95
Water (normal, 62° F.), calculated	1 “	998.91	2.20222	15,415.50
Mercury (32° F., sp. gr. 13.593)	1 cu. in.	222.76	.49111	3,437.77
Do., calculated	1 cu. ft.	....	848.58790	....
Air (dry, 0° C., 760 mm.), Regnault	1 liter	1.293187	.002851	19.957
Air (dry, 32° F., 29.92 in.), calculated	1 cu. ft.	36.617	.080728	565.096
Air (dry, 60° F., 30 in.), calculated	1 cu. ft.	34.738	.076585	536.095
Hydrogen (0° C., 760 mm.), Regnault	1 liter	.089578	....	1.382400
Hydrogen (32° F., 29.92 in.), calculated	1 cu. ft.	2.536	.005592	39.144

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NOTE.—Numbers refer to pages. Letters used as abbreviations relate to words in the same line, or in the title or heading under which they stand.

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